Expert Guide

Part 1 Responsive Building Concepts

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IEA ECBCS Annex 44 Integrating Environmentally Responsive Elements in Buildings

Expert Guide – Part 1 Responsive Building Concepts

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International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

Foreword

This guide summarizes the work of Subtask B of IEA-ECBCS Annex 44 “Integrating Environmentally Responsive Elements in Buildings” and is based on the contributions from the participating countries.

The publication is an official Annex report. With a focus on innovative building concepts that dynamically respond to changes in climate and user demands, the report describes building concepts, design methods and tools that have been tested in theory and practice in buildings around the world.

This guide is aimed at designers and consultants and describes the principles of responsive building concepts, their benefits and limitations, economical feasibility and impact on energy savings, company image, comfort, productivity, building functionality and flexibility and gives guidance on design of these concepts, including integration of responsive building elements and HVAC-systems and build examples, and for rough evaluation of building performance

It is hoped, that this guide will be helpful in the search for new solutions in the built environment and to the problem of designing and constructing sustainable buildings.

Per Heiselberg

Editor

Acknowledgement

The material presented in this publication has been collected and developed within an Annex of the IEA Implementing Agreement Energy Conservation in Buildings and Community Systems, Annex 44 “Integrating Environmentally Responsive Elements in Buildings”.

The report is the result of an international joint effort conducted in 12 countries. All those who have contributed to the project are gratefully acknowledged. A list of participating institutes can be found on page XX.

The University of Hong Kong, Hong Kong China has been an associated member of the Annex and has contributed to the work in all subtasks. The contributions of Yuguo Li, Lina Yang and Matthias Haase to the project and outcome are gratefully acknowledged.

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On behalf of all participants the members of the Executive Committee of IEA Energy Conservation in Buildings and Community Systems Implementing Agreement as well as the funding bodies are also gratefully acknowledged.

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1. Introduction

Energy use for room heating, cooling and ventilation accounts for more than one third of the total, primary energy demand in the industrialised countries, and is in this way a major polluter of the environment. To successfully achieve the targets set out in the Kyoto protocols it is necessary to identify innovative energy technologies and solutions for the medium and long term which facilitates the implementation and integration of low carbon technologies, such as renewable energy devices, within the built environment. Deployment of low carbon technologies still faces major barriers in the built environment especially in relation to costs, building logistics, technological challenges, lack of understanding and knowledge and absence of requisite skills.

Research into building energy efficiency over the last decades has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components (windows, daylighting, ventilation, etc.) and building equipment such as heating, ventilation, cooling equipment and lighting. Significant improvement have been made, and most building elements still offer opportunities for efficiency improvements.

But the greatest future potential lie with technologies that promote the integration of responsive building elements with the building services and renewable energy systems. Responsive in this context means ability to dynamically adjust physical properties and energetic performance according to changing demands from indoor and outdoor conditions. This ability could pertain to energy capture (as in window systems), energy transport (as air movement in cavities), and energy storage (as in building materials with high thermal storage capacity).

With the integration of responsive building elements, building services and renewable energy systems, building design completely changes from design of individual systems to integrated design of responsive building concepts, which should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices.

The objectives of IEA ECBCS Annex 44 is to collect information about the performance of buildings that utilize responsive building systems, and improve and optimise such system.

This design guide describes the principles of responsive building concepts, their benefits and limitations, impact on energy savings, comfort and building functionality and flexibility and gives guidance on design of these concepts, including integration of responsive building elements and HVAC-systems as well as build examples.

1.1 Aim and Physical Idea

In a responsive building concept an optimum must be found between the, sometimes contradictory requirements from energy use, health and comfort. From the viewpoint of human coexistence with nature the approach is to make buildings “open” to the environment and to avoid barriers between indoors and outdoors, while from the viewpoint of energy savings the approach for certain periods is to exclude the buildings from the environment. The transition between indoors and outdoors herewith becomes a more or less hybrid zone were the energy gains are not only rejected, but are stored, tempered, admitted or redirected, depending on the desired indoor conditions.

In this respect responsive building elements (RBE) are essential technologies for the exploitation of the environmental and renewable energy resources and in the development of responsive building concepts the challenge is to achieve an optimum combination of responsive building elements and integration of these with the building services systems and renewable energy systems to reach an optimal environmental performance. Therefore, the development and implementation of responsive building elements are considered to be a necessary step to increase the energy efficiency of buildings.

From the viewpoint of energy, responsive building elements can be characterised in three categories: heat flux related RBE's, ventilation (permeability) related RBE's and energy (thermal) storage related RBE's. Although some RBE’s can be part of two or all three categories.

Heat flux related RBE’s have a variable (adaptive) thermal insulation performance. The characteristic feature of this category is that the heat flow is proportional to the insulation level and a certain separating area, for instance the glass area or the facade area. Examples of this category of RBE’s are double skin facades and dynamic insulation. Heat flux related RBE's can reduce the demand for heating and cooling by increasing the insulation level in winter and decreasing it in summer. Heat flux related RBE's can also control the amount of solar energy that is transmitted through the windows. The important properties of heat flux related RBE's are the area of the facade, its U-value and the g-values of the glazing.

Thermal energy storage related RBE’s have a capability to store (thermal) energy in time periods with excess heat and to release this energy again in periods with a heating demand and therefore leads to a reduction of the total energy demand. Examples of this type of RBE’s are earth coupling systems, thermal mass activation and PCM. The important properties of energy storage related RBE's are the total amount of energy that can be stored at a given temperature difference and the time constant of the storage which controls how fast the RBE can store and release energy. With the time constant the energy related RBE's can further be subdivided in:

- short term thermal active (time-scale: a day)
- medium term thermal active (time-scale: a week)
- long term thermal active (time-scale: a month to a year)

Transparency related RBE’s have a variable transparency with regard to solar radiation and daylight. The characteristic feature of this category is the choice of transparent material and how its transparency depends of the radiation wavelength (mainly heat or mainly daylight). Examples of this type of RBE’s are mainly fenestration and glazed facades.

Figure 1.1 illustrates different responsive building elements and their typical physical behavior (category).

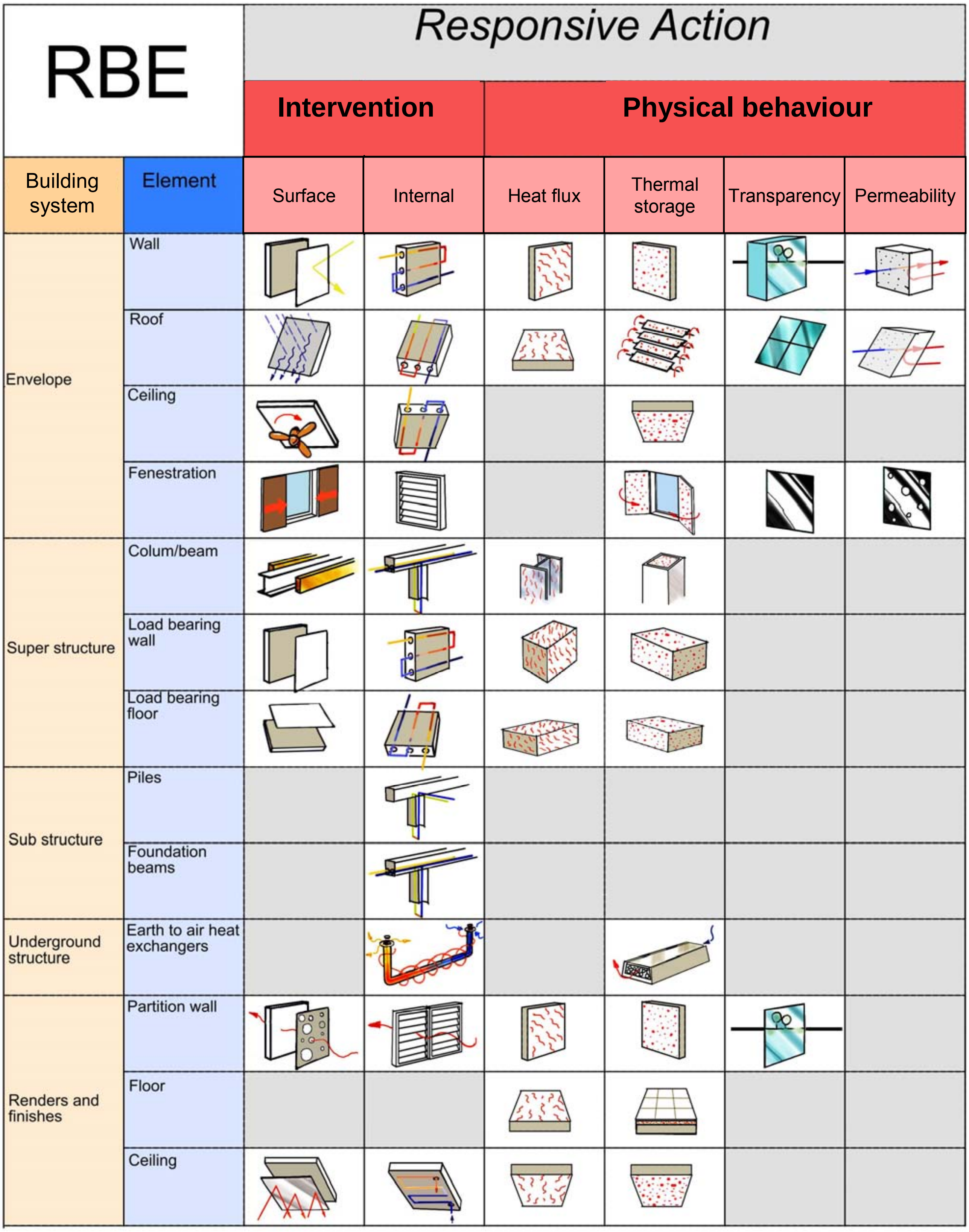


Figure 1.1 Illustration of categories and responsive actions of responsive building elements.

Permeability (Ventilation) related RBE’s have a variable (adaptive) permeability, i.e. ventilation performance. The characteristic feature of this category is that the heat flow is proportional to an air flow rate. Examples of this type of RBE’s are ventilated facades and embedded ducts. By regulating the flow of outside air the heat exchange with the outside is controlled. Some ventilation related RBE's include pre-heating of the air before it enters the building. The air flow rate and the pre-heat/pre-cool temperature are the important properties to quantify a ventilation related RBE.

In the figure the illustrated responsive elements are along the vertical axis divided according to their location and structural function in the building. For each responsive element information given along the horizontal axis relates firstly to the mechanism of interaction with the environment and HVAC system, which can either be via the surface of the element or via the interior. Secondly, information is given about the category of the element. The four categories describes the physical behavior, which can be related to heat flux, thermal storage, permeability (ventilation) or transparency (daylight and solar radiation).

1.2 Definition of Terms

In order to ensure a common understanding of the terms used in this publication these are defined in the following.

***Responsive*:** according to the Oxford Dictionary, responsive means ‘responding readily and positively’ with responding meaning in this context: ‘do something as a reaction’.

***Intelligent*:** when speaking of an ‘intelligent’ device, literally it means the ‘ability to vary its state or action in response to varying situations and past experience’. This implies the presence of a computer or a central control centre, since past experiences are used to determine the action to be undertaken next and they are active systems that can act independently of human interference.

Smart: “having an embedded intelligence”, meaning that the device is capable of acting in an intelligent way by itself. This implies not necessarily the need for integration of computers and electronics. Materials that adjust their characteristics under the direct influence of the environment, such as photochromic glass that changes colour when exposed to (bright) light, can be considered as a smart material/device.

Responsive Building Elements are defined as building construction elements which are actively used for transfer and storage of heat, light, water and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting. The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment. Examples include:

- Facades systems (ventilated facades, double skin facades, adaptable facades, dynamic insulation)
- Foundations (earth coupling systems, embedded ducts)

- Storages (active use of thermal mass, core activation for cooling and heating, application of phase change materials (PCM))
- Roof systems (green roof systems)

Responsive Building Concepts are design solutions of optimized responsive building elements, building services systems and energy-systems integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. It follows that responsive building concepts are design solutions:

- that maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention
- that develop from an integrated multidisciplinary design process, which optimises energy efficiency and includes integration of human factors and architectural considerations.

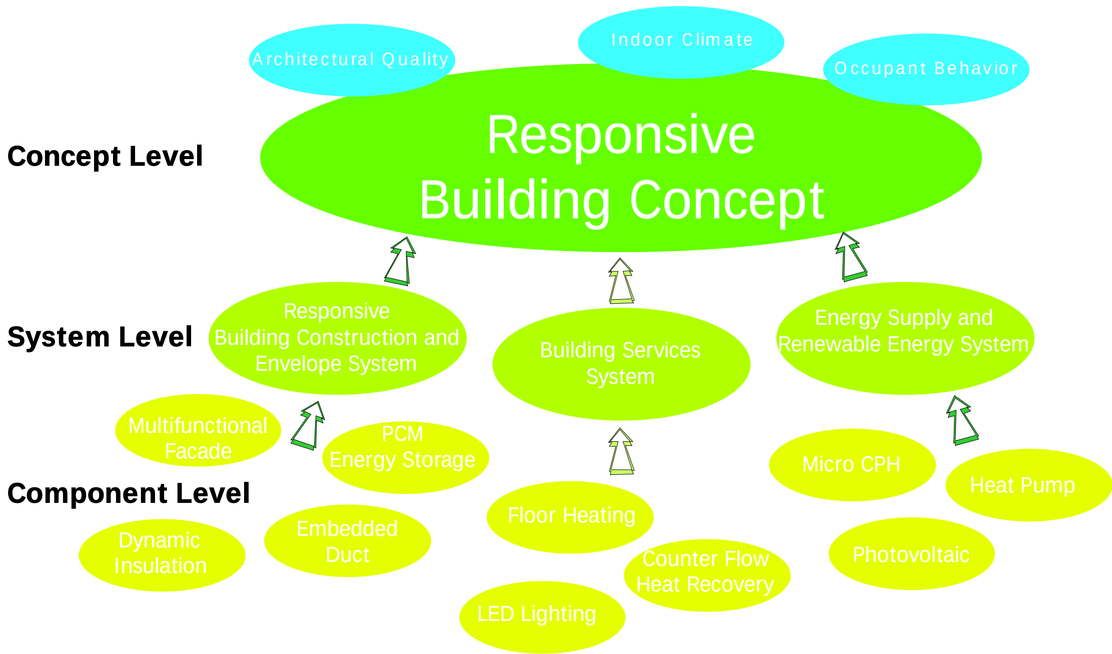


Figure 1.2. Illustration of the Responsive Building Concept.

Integrated Building Concepts are a whole building concept that includes all aspects of building construction (architecture, facades, structure, function, fire, acoustics, materials, energy use, indoor environmental quality, etc…). It consist of three parts, (Heiselberg et al. 2006):

- the architectural building concept,
- the structural building concept and
- the energy and environmental building concept

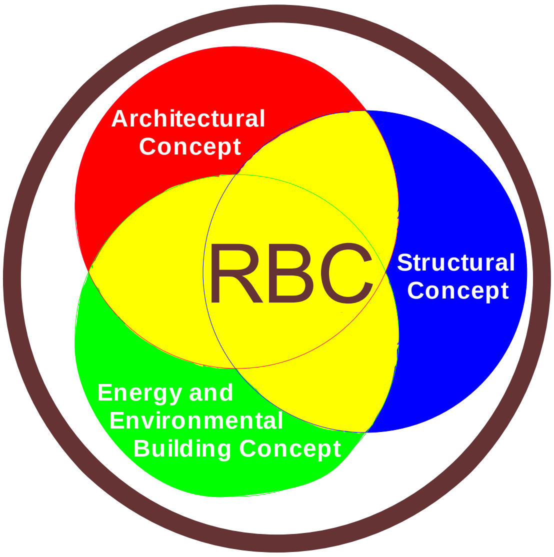


Figure 1.3. Illustration of the Integrated Building Concept.

These three concepts correspond to the three different main professions involved in building design and each concept is developed in parallel by the three professions using their own set of methods and tools - but in an integrated design process leading to an integrated solution – the Integrated Building Concept.

Integrated Building Design is a design process where design teams consisting of architects, engineers and other consultants develop the building design in an iterative process from the conceptual design ideas to the final detailed design. Building energy use as well as the size of HVAC and energy systems are reduced without the use of sophisticated technologies, but only through an effective integration of the architectural, structural, HVAC and energy designs. The integrated design approach achieves this improved energy utilisation due to the relationship that exists between the building structure, its architecture, the HVAC systems and the renewable energy systems. Besides this the integrated design approach typically also achieves an improvement in the environmental performance of the building, as well as fewer construction problems and lower costs

Environmental performance comprises energy performance with its related indoor environmental quality (IEQ) as well as energy related resource consumption, ecological loadings

1.3 Rationale for Application of Responsive Building Concepts

Integration of responsive building elements, building services systems and energy systems in responsive building concepts have a number of important advantages:

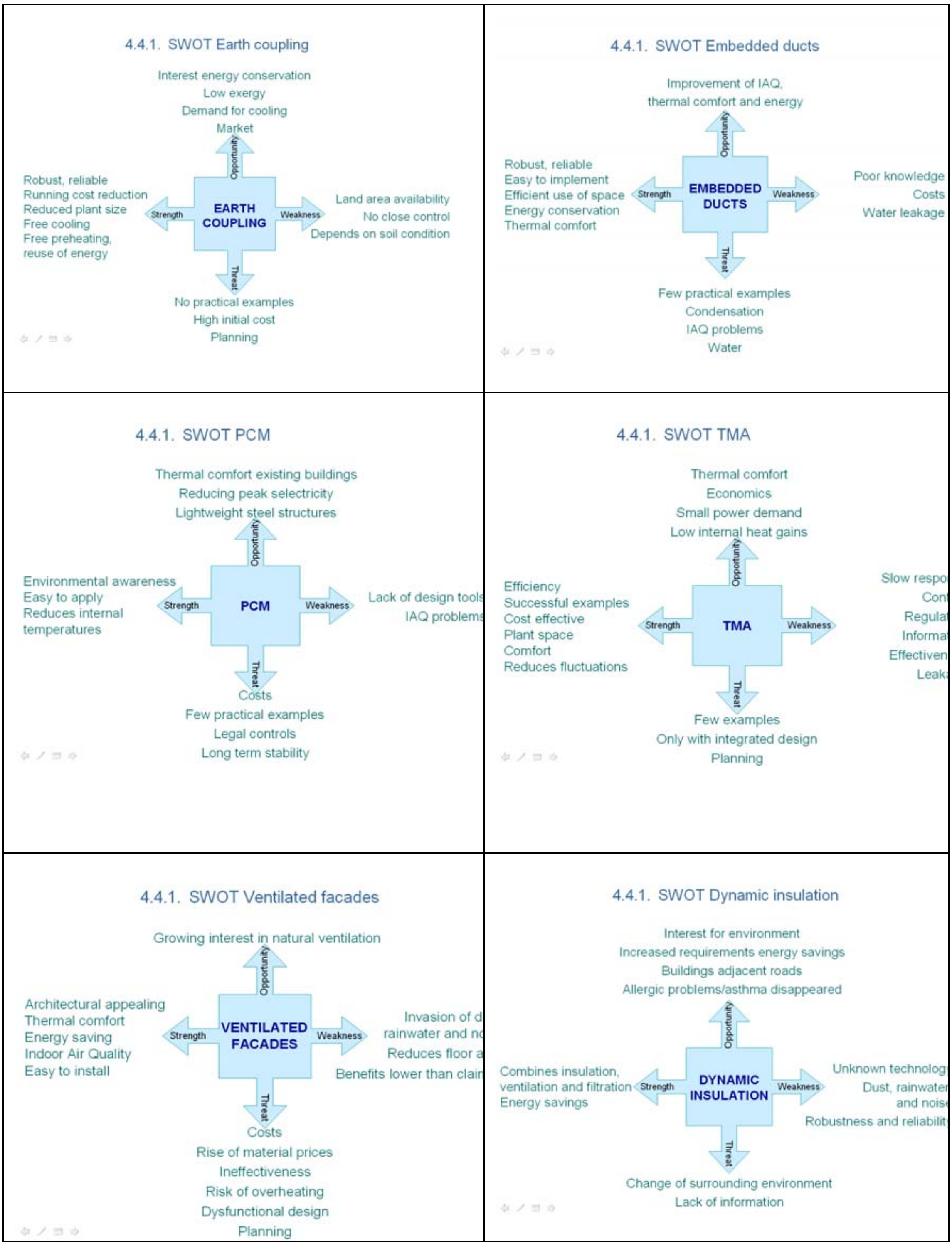
- Integration of responsive building elements with building services systems and energy systems will lead to substantial improvement in environmental and operating cost performance.
- It enhances the use and exploits the quality of energy sources (exergy) and stimulates the use of renewables and low valued energy sources (like waste heat, ambient heat, residual heat etc.)
- It will further enable and enhance the possibilities of passive and active storage of energy (buffering)
- It will integrate architectural principles into energy efficient building concepts
- Responsive building elements lead to a better tuning of available technologies in relation to the building users and their behaviour
- It enhances the development of new technologies and elements in which multiple functions are combined in the same building element.
- It will lead to a better understanding of integrated design principles among architects and engineers.

1.4 Driving forces and Barriers for Application of Responsive Building Concepts

Within the framework of the IEA Annex an enquiry has been held among the participants to get an impression about the tendencies in the building sector, regarding the application of Responsive Building Elements and Integrated Building Design concept in general and new developments, building regulations, driving forces and opportunities. The enquiry is not necessarily a scientific validated representation of the situation in the mentioned country, but more or less describes the personal view of the interviewed experts.

1.4.1 Responsive building elements

By far the main driving force in all countries for RBE’s and IBC’s is the growing need and awareness for energy savings in the build environment. This, together with increasing requirements for better health and IAQ in buildings. The accents, attention points and organisation of the building sector can differ quite a lot and are based on the economic situation per country, region and city, the building background (materials used, the regulations an the building process and organisation), etc. This makes it difficult to draw general conclusions and give general guidelines to apply. For the detailed information per country the summary of enquiry per country gives more information in detail. In general the following general remarks were given on the application of RBE’s in the building sector: There is a lack of knowledge, information and guidelines, successful examples and expertise. These issues form a barrier for application. For future components energy reduction, improvement of IAQ and comfort, together with cost reduction, quality improvement, improved productivity and failure reduction are considered to be important. Per RBE a scheme of a SWOT-analysis based on the enquiries has been constructed and is given below:



1.4.2 Integrated building concepts and integrated design

Also the specific situation and background per country makes it very difficult and complicated to draw general conclusions about the specific aspects for integrated building concepts and an integrated design process. Each country has it's shining examples and it's own typical barriers that come forward from the building tradition, the historical grown position of parties involved, etc. The main barriers to come to an integrated design process are:

- The lack of interest, awareness, know-how, willingness and skills at the parties involved.
- The lack of drives for changing the present situation, easy to use suitable instruments, tools and guidelines, information and the lack of interest for integrated design.
- The lack of a common language and "feelings" between architects and engineers
- The lack of easy-to-use suitable instruments, the strict demand for initial cost reduction, lack of knowledge and understanding between architects and engineers
- Lack of public understanding for an integrated design process.
- Willingness of all members of the design team.

It can be concluded that a number of issues have to do with mentality in the sector, willingness to change etc. On the other hand: lack of suitable information and skills also seems a barrier. This last barrier can hopefully be changed by the contents of this booklet.

2. Integrated Design Process

2.1 Integrated Design Philosophy

2.1.1 Background

In the first half of the 20th century, HVAC systems and artificial lighting were developed to meet indoor comfort needs. Before the introduction of mechanical systems, climate – not building style or appearance – was the major determinant of building form. Comfort was achieved through passive means and architectural features built into the design. However, with the advent of new technologies, architects were no longer constrained by the need to ensure that buildings had ample daylighting, remained airy and cool in the summer and warm in the winter. Since HVAC systems and artificial lighting could satisfy comfort needs, architects could pursue unrestricted designs without making comfort part of the architectural design.

These innovations started a design revolution. With the freedom to pursue the architectural design as a pure art form, the architect created a design and then passed it on to the constructional and HVAC designers to “fit” the equipment needed to achieve comfort. The design process that at one time integrated all design disciplines evolved into a sequential process carried out in separate disciplines. The usual interaction between HVAC designers and architects no longer occurred, which severely handicapped each discipline’s ability to contribute to the overall design. The result was buildings that were not designed to coexist with the surrounding climate and not to be environmentally sustainable, resulting in the development of poor concept design choices, thereby providing sub-optimal performance and buildings that were energy intensive, costly to operate and had a significant effect on the environment.

2.1.2 Recognition of the environmental design - integrated design approach

Before the advent of modern design practices, buildings were protected from the inclement weather or designed to take advantage of fair weather through orientation and strategic placement of entrances and windows. Similarly, the use of natural lighting was planned into the building design. Architects utilised a number of design features such as atriums, light shelf’s, or narrow building designs to bring natural lighting into building interiors. Other techniques were also used to keep buildings comfortable in the summer, ranging from finishing the building exterior in light colours to introducing natural ventilation via thermal stacks. In contrast modern construction seldom considered orientation, building shape, daylighting features or passive cooling techniques. Clearly, there was a need for architects and HVAC designers to consider the implications of building design on the resulting energy use. This ultimately required the development of a process that emphasised the use of passive (i.e., weather integration) and active (i.e., mechanical systems) techniques to meet all comfort needs.

Today, the construction industry is in the early phases of a revolution to reinvent the design process that was used before the advent of HVAC equipment. Design teams including both architects and engineers are formed and the building design is developed in an iterative process from the conceptual design ideas to the final detailed design. Building energy use and HVAC equipment size are reduced not only by the use of sophisticated technologies, but also through an effective integration of the architectural design and HVAC technologies. The integrated design approach achieves this improved energy utilisation due to the relationship that exists between the building, its architecture and the HVAC equipment. Besides this the integrated design approach also enhances environmental performance of the building, as well as leads to fewer construction problems and reduces lift cycle costs.

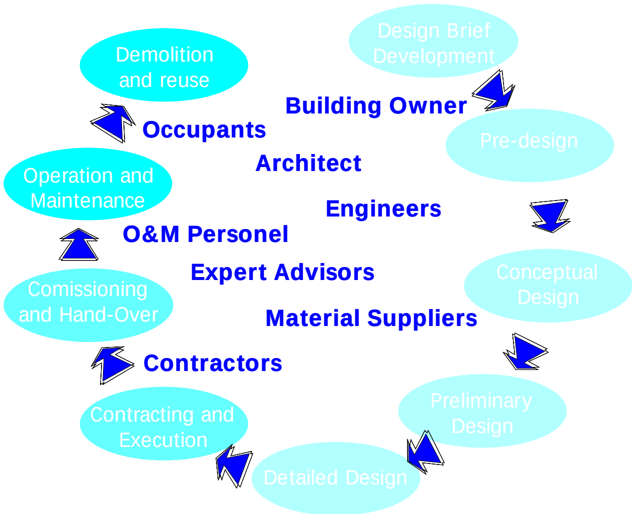


Figure 2.1. Integrated design process.

2.1.3 Motivation and benefits of the integrated design process

The most important advantage of the integrated design approach is illustrated in figure 2.2. The figure indicates how the effectiveness of decisions declines during the various phases of the life of a building. The effectiveness is defined as the relation between the impact of the decision on the final building performance and the cost of the action needed to implement the decision. The decisions made early have the greatest impact on the performance and the efficiency of a building for its entire 50- or 100-year life, while the cost often is minimum.

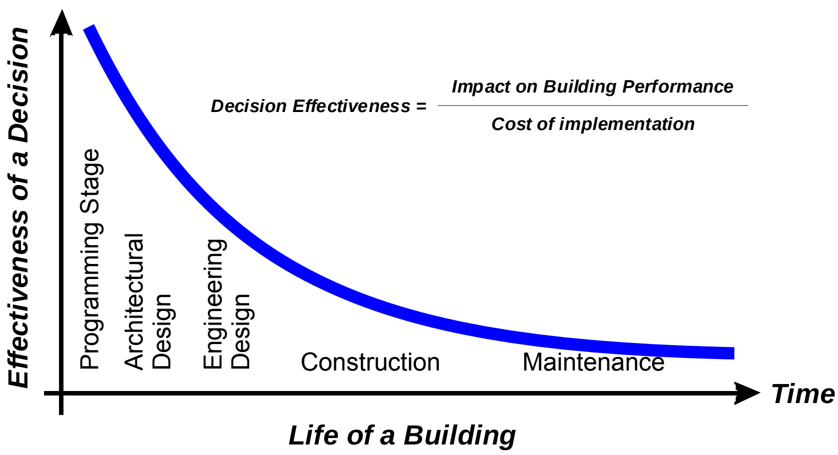


Figure 2.2. Effectiveness of decisions made in different phases of a buildings lifetime.

In a sequential design process it is much harder for an engineer at the later phases of design to have the same impact as the architect has at the conceptual design phase and the risk that poor design concepts are developed are therefore higher.

There are a number of serious consequences if the proper decisions are not made at the conceptual design phase. The building will almost certainly cost more to build and operate (e.g. it often takes huge air conditioning equipment and much energy to compensate for poor orientation, window placement etc.). The cost is not only in terms of money, but also in the depletion of non-renewable resources, in the degradation of the environment and often also in poorer building performance in terms of comfort. In-efficient buildings contribute significantly to pollution and the greenhouse effect, which is likely to negatively alter life on earth.

An integrated design process ensures that the knowledge and experience gained by an analytical consideration of design is formalized, structured and incorporated into the design practice.

In the integrated design process the expertise of the engineers is available from the very beginning at the preliminary design phase and the optimization of the architectural and HVAC designs can start at the same time as the first conceptual design ideas are developed. The result is that participants contribute their ideas and their technical knowledge very early and collectively. The concepts of energy and building equipment will not be designed complementary to the architectural design but as an integral part of the building very early.

More detailed information about the principles and methods of the integrated design process can be found in the publications of IEA-SHC Task 23: "Optimization of Solar Energy Use in Large Buildings", which focused on the development of integrated design principles and methods, /Larson and Poel, 2003; Löhnert et al (2003)/.

2.1.4 Implementation barriers

A number of barriers appear when the borderline between architecture and engineering is crossed and the design process contains a lot of challenges to the persons or groups who participate in the process.

Architects belong to the humanistic arts tradition while the engineer belongs to a technical natural science tradition. This often creates problems for architects and engineers working as a team, as the communication between the two groups rely on a common language and in this case the languages are at the outset very different.

The integrated design process is a holistic method that intertwines knowledge elements from engineering with the design process of architecture to form a new comprehensive strategy to optimize building performance. This implies evaluation and weighting of very different building performance characteristics that often are non-comparable, which requires willingness from all participants to reach acceptable compromises.

The goal of integrated design is an improved and optimized building performance for the benefit of the building owner and the occupants. Changes in design process and methods will require investment in education and will always be more expensive for the designers in the beginning. Therefore it cannot be expected that architects and engineering consultants will be the main drivers for these changes unless the building owners and clients recognize the benefits and are willing to contribute to the investments needed to implement the changes.

2.2 Design Strategy

2.2.1 Design Strategy and boundary conditions

As in the classical design approach a sustainable design should start with an thorough analysis of the environmental conditions and determine the beneficial environmental design conditions as location of the building, sheltering, optimal orientation, solar and wind optimization and protection, ground coupling possibilities etc. This mostly takes place in relation to the architectural and esthetical design considerations, but is the first step in achieving an more energy saving design.

Next to it, the aimed for inner conditions as comfort requirements and IAQ need to be considered. Fixed and uniform conditions as stated in the last decades can be transformed in adaptive conditions, related to the place, function, time and activity in the building. Also the consideration to go with local climates can lead to a large energy saving potential.

2.2.2 Design Strategy and Technical Solutions

In order to reach an integrated design solution and develop a Responsive Building Concept it is necessary to define and apply a certain design strategy. In Annex 44 the design strategy is based on the method of the “Kyoto Pyramid”, see figure 2.3

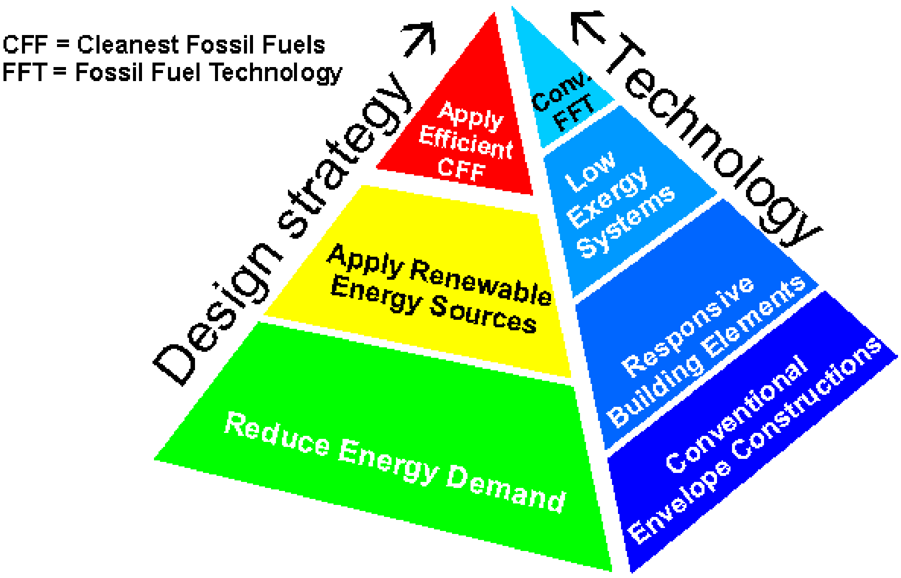


Figure 2.3. Illustration of Annex 44 Design Strategy and corresponding Technologies

The *Kyoto Pyramid* (KP) is a strategy that has been developed for the design of low energy buildings in Norway, (Dokka and Rødsjø, 2005). It is based on the Trias Energetica method described by Lysen (1996). The left side of the pyramid shows the design strategies, and the right side of the pyramid shows the techical solutions that may be applied in each of the steps. The figure clearly positions the responsive building elements as a technology that falls in the first step "reduction of energy demands" as well as in the second step "application of renewable energy sources".

The integrated design strategy start at the bottom of the pyramid, applying the strategies and technologies as follows:

1. Reduce Demand

   Optimize building form and zoning, apply super insulated and air tight conventional envelope constructions, apply efficient heat recovery of ventilation air during heating season, apply energy efficient electric lighting and equipment, ensure low pressure drops in ventilation air paths, etc.

   Apply Responsive Building Elements if appropriate including advanced façades with optimum window orientation, exploitation of daylight, proper use of thermal mass, redistribution of heat within the building, dynamic insulation, etc.

2. Apply renewable energy sources

   Provide optimal use of passive solar heating, dayligthing, natural ventilation, night cooling, earth coupling. Apply solar collectors, solar cells, geothermal energy, ground water storage, biomass, etc. Optimise the use of renewable energy by application of low exergy systems.

3. Efficient use of fossil fuels

   If any auxiliary energy is needed, use the least polluting fossil fuels in an efficient way, e.g. heat pumps, high-efficient gas fired boilers, gas fired CHP-units, etc. Provide intelligent control of system including demand control of heating, ventilation, lighting and equipment

The main benefit of the method is that it stresses the importance of reducing the energy load before adding systems for energy supply. This promotes robust solutions with the lowest possible environmental loadings.

2.2.3 Application of the Design Strategy

Application of the strategy in the conceptual and preliminary design phase heating, cooling, lighting and ventilation of buildings can be accomplished in the following way, see figure 2.4.

Step 1: Basic design focusing on reduction of energy demands

The first step is to establish the function of the building envelope as the primary climatic modifier, supported by the services to trim conditions. The focus is primarily on design of the building itself to minimise heat loss in winter, to minimise heat gain in summer, and to use light and fresh air efficiently in order to reduce demands for heating, cooling, lighting and ventilation.

Priority in this is the reduction of internal and external heat loads. The internal heat loads can be reduced by the use of energy saving equipment as computers, copiers etc and by installing energy saving electric lighting. Most effective in this is the maximizing the daylight autonomy of rooms and thus reducing the energy use for electric lighting. As the efficacy of daylight is much higher that artificial light this counts both for reduction of electric energy consumption for lighting as for reducing the energy consumption for cooling.

The next step is to find an optimum in reducing the heating and cooling gains by an optimal surface to volume ratio, zoning, shading, insulation level and a demand controlled ventilation level. A special effort is required when applying long term heat storage. In that case heating and cooling gains over a year need to be tuned to each other to avoid long term imbalance.

Decisions at the first step determine the size of the heating, cooling and lighting loads and good fabric design is essential for minimising the need for services. Poor decisions at this point can easily double or triple the size of the mechanical equipment needed. Where appropriate, designs should avoid simply excluding the environment, but should respond to factors like weather and occupancy and make good use of natural light, ventilation, solar gains and shading, when they are beneficial.

At an early phase, it should be possible to modify the design to reduce the capacity, size and complexity of the building services, which can reduce the capital cost of the services without having to remove features from the design.

Step 2: Climatic design though optimization of passive technologies

At an early phase, it should be possible to modify the design to reduce the capacity, size and complexity of the building services, which can reduce the capital cost of the services without having to remove features from the design.

The second step involves optimisation of natural and “free” gains from sun, wind and thermal storage through application of direct solar gains, free cooling, thermal mass application and natural ventilation. Effective functioning of these measures directly relates to the outdoor climate as available wind and sun conditions, day-night rhythm and earth temperature.

Proper decisions at this point can greatly reduce the loads as they were created during the first step leading to the wanted reduction in size and complexity of the building services.

Step 3: Integrated system design and application of responsive building elements

Step 3 contains the design of integrated systems with responsive building elements. In this step the activation of building elements by building services enhances the further employment of building components. Energy gains in building elements are actively controlled by changing and influencing the physical behaviour and properties of the building components. Examples of the performance of these responsive building elements are further described in detail in chapter 2.

Step 4: Design of low exergy mechanical systems

To realise the comfort conditions required, mechanical systems for heating, cooling, lighting and ventilation are applied to handle the loads that remain from the combined effect of the previous steps. To enhance the application of renewable energy sources priority lies with low exergy mechanical systems. This counts for the energy generation part, the energy distribution part and the energy delivery part of the mechanical systems. Hereby a tuning of generation, distribution and delivery is crucial to reach an efficient and optimal performance.

In general, a “simple” approach is the best way of promoting good installation, operation and maintenance. Simple services promote good understanding of how the building and plant is intended to work. This generally improves building management and hence energy efficiency.

More detailed information about low exergy mechanical systems are available from IEA ECBCS Annex 37: “Low Exergy Systems for Heating and Cooling” and Annex 49: “Low Exergy Systems for High Performance Buildings and Communities”, /Annex 37, Annex 49/.

Step 5: Efficient design of conventional mechanical systems

Step five consists of designing the (conventional) building services to handle the loads that remain from the previous steps. Herewith it is important to ensure that the services operate in harmony without detrimental interaction or conflict. Many energy problems can be traced to a conflict between building services and many conflicts between services are control issues. An energy efficient design strategy should avoid this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward. It is not a good policy to hope that the control system will resolve the conflicts.

Step 6: Design of intelligent control for optimized operation

Definitely more than in the past the intelligent control of the energy transport is crucial to come to a proper and efficient operation of the building, building services and renewable energy systems to reach an optimal energy efficiency. The systems therefore needs to be fed with the design considerations and must be able to tune to the different external and internal climate conditions and the comfort requirements of the building occupants. Advanced sensor techniques together with sophisticated control algorithms are still under development and need further improvement which is also the case for interfaces for user control and user/system interaction.

	Heating	Cooling	Lighting	Ventilation
Step 1 Basic Design	*Conservation* 1. Surface to volume ratio 2. Zoning 3. Insulation 4. Infiltration	*Heat Avoidance* 1. Façade Design 2. Solar Shading 3. Insulation 4. Internal heat gain control 5. Thermal mass	*Daylighting* 1. Room height and shape 2. Zoning 3. Orientation	*Source Control* 1. Surface material emission 2. Zoning 3. Local exhaust 4. Location of air intake
Step 2 Climatic Design	*Passive Heating* 1. Direct solar heat gain 2. Thermal storage wall 3. Sunspace	*Passive Cooling* 1. Free cooling 2. Night cooling 3. Earth cooling	*Daylight Optimization* 1. Windows (type and location) 2. Glazing 3. Skylights, light-wells 4. Light shelves	*Natural Ventilation* 1. Windows and openings 2. Atria, stacks 3. Air distribution
Step 3 Integrated System Design	*Application of Responsive Building Elements* 1. Intelligent facade 2.Thermal mass activation 3. Earth coupling 4. Control strategy	*Application of Responsive Building Elements* 1. Intelligent facade 2.Thermal mass activation 3. Earth coupling 4. Control strategy	*Daylight Responsive Lighting Systems* 1. Intelligent façade 2. Interior finishes 3. Daylight control strategy 4. …	*Hybrid Ventilation* 1. Building integrated ducts 2. Overflow between rooms 3. Control strategy 4. …
Step 4 Design of Low Exergy Mechanical Systems	*Low Temperature Heating System* 1. Application of renewable energy 2. Floor/wall heating 3. …	*High Temperature Cooling System* 1. Application of renewable energy 2. Floor/wall cooling 3. …	*High Efficiency Artificial Light* 1. LED 2. …	*Low Pressure Mechanical Ventilation* 1. Efficient air distribution 2. Low pressure ductwork, filtration and heat recovery 3. Low pressure fan 4. …
Step 5 Design of Conventional Mechanical Systems	*Heating System* 1. Radiators 2. Radiant panels 3. Warm air system	*Cooling System* 1. Cooled ceiling 2. Cold air system	*Artificial Lighting* 1. Lamps 2. Fixtures 3. Lighting control	*Mechanical Ventilation* 1. Efficient air distribution 2. Mech. exhaust 3. Mech. ventilation
Step 6 Intelligent Control	Advanced sensor techniques, model based and adaptable control algorithms, user interface, ….			

Figure 2.4. Typical design considerations at each design phase.

The heating cooling, lighting and ventilation design of buildings always involves all steps whether consciously considered or not. As mentioned before, minimal demands have in the recent past been placed on the building itself to affect the indoor environment. It was assumed that it was primarily the engineers at the fifth step which were responsible for the environmental control of the building. Thus architects, who were often indifferent to the heating and cooling needs of buildings, sometimes designed buildings with large glazed areas for very hot or very cold climates, and the engineers would then be forced to design giant heating and cooling plants to maintain thermal comfort. On the other hand, when it is consciously recognised as in an integrated design process that each of these steps is an integral part of the heating, cooling, lighting and ventilation design, better buildings result.

The buildings are better for several reasons. They are often less expensive because of reduced mechanical equipment and energy needs. Frequently they are also more comfortable because the mechanical equipment does not have to fight such giant loads. Buildings and services are often responsive to the needs of the occupant and therefore generally more successful in achieving comfort, acceptability and efficiency. Occupants usually prefer some means of altering their own environment while management will require good overall control of systems.

The importance of a comprehensive approach to energy utilisation is illustrated by a parametric study conducted for the design of a new office building in Copenhagen., where the influence of the glazing area relative to the total facade area on primary energy consumption was modelled. Any increase in glass area facing east or west resulted in increased heating or cooling demands. The obvious conclusion based on this condition alone would be to minimise the glass area. Conversely, increasing the glass area to 45% of the facade area strongly decreases the electricity demand for lighting. When primary energy demand for heating, cooling and lighting are considered together, then increasing the glass area to 40% of the facade area results in increased total energy savings, see figure 7. The savings in electricity from daylighting have a dominant influence because of the assumption that thermal energy is produced with an efficiency of 67% versus an efficiency of 27% for energy in the form of electricity. It should be emphasized that the conclusions will always be case specific as they depend on the specific climate, the type of energy production and distribution, the type of glazing, etc.

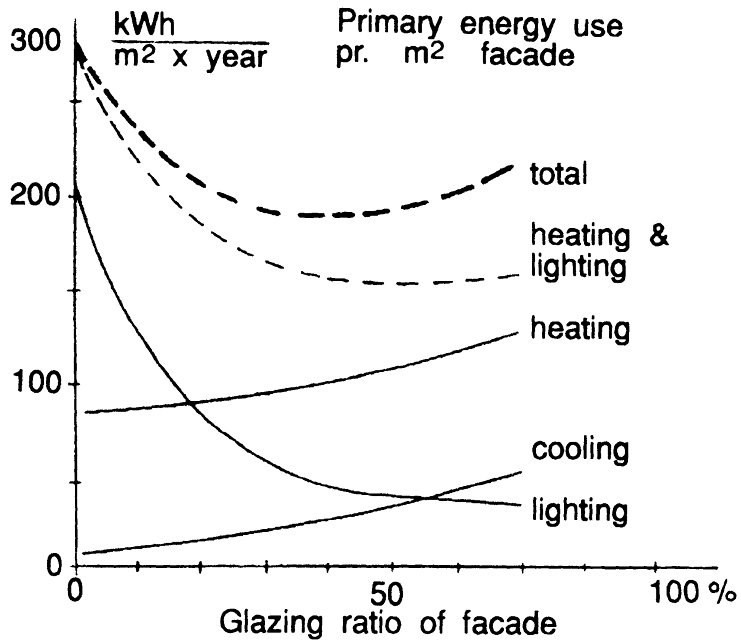


Figure 2.5. Primary energy use per m² double glazed windows facing east or west in Copenhagen. /Kristensen and Esbensen/

2.3 Annex 44 Integrated Design Process

The Integrated Design Process, IDP, creates a synergy of competencies and skills throughout the process by the inter-disciplinary work between architects, engineers, costing specialists, O&M personel and others right from the beginning of the process. It ensures that different knowledge of specialists is introduced at an early project phase and takes into account a wide variety of opportunities and options from the very outset. It involves modern simulation tools, and leads to a high level of systems integration. It enables the designer to control the many parameters that must be considered and integrated, when creating more holistic sustainable buildings. All of this can allow clients to reach a very high level of performance and reduced operating costs, at very little extra capital outlay.

The method is coping, as well with technical, as aesthetical problems that must be solved in an integrated building design, and focuses on the creative element in the process, in order to identify new opportunities and make innovative solutions in a new building design. Therefore the architect's artistic approach to the creation of ideas, and the ability to see new possibilities and to work strategic and interdisciplinary with designing architecture in interaction with the engineers strategic and creative ideas for development of the energy and environmental concept are very important. And by doing that without loosing the creativity in the process is always very important in the process designing new integrated building concepts.

2.3.1 Main Design Phases

The integrated design process works with the architecture, the design, functional aspects, energy consumption, indoor environment, technology, and construction e.g. It is important to consider the whole process, structuring it into clearly defined sequences to improve the overview of goals, activities, actors and products and to switch between them in a timely and content-based manner, because the roots of many problems can frequently be traced to faulty or inadequate preparation.

The traditional overall linear design procedure marked by milestones reflecting a series of rough phases is necessary both in terms of the organization of the collective decision making and for the efficient division of tasks and work. In this view, the sequential linear process is an organizational prerequisite with the building design logically structured into chronological sequences.

In contrast to this overall linear process, the intermediate workflows of involved actors in each rough phase are far from being linear. Such workflows can be characterized by iteration loops, see figure 2.6.

These loops provide problem-oriented analyses of design alternatives and optimization based on the design strategy presented in figure 2.4 and taking into consideration input from other specialists, influences from context and society that provide possibilities and/or limitations to design solutions as well as evaluates the solutions according to the design goals and criteria.

The actual design process is made up of a number of roughly-defined phases which demand for individual iterations within the phases and accompanied by a continuous review of project goals, objectives and criteria which serve as a "roadmap" throughout the entire design process.

The nature of the iterations vary between the phases depending on the depth of the problems considered and will impose different emphasis on different steps in the design strategy. They are also characterized by shifts between problems defined and corresponding solutions obtained according to the actual phase in the design process.

Designers need to be mindful of the interfaces between the iterative workflows, which are characterised by initial tasks, (interim or partial) results and findings at the end. These transitions, acting as interfaces between two design phases, need to be organised by a qualified project management, which uses clear decisions and careful process documentation to prevent any losses of information.

The design flow of Responsive Building is shown in Figure 2.6. The Annex 44 **I**ntegrated **D**esign **P**rocess (IDP) includes the following main phases:

PHASE 1

Where to built - Building location

It is essential to understand the climate characteristics of the building site for responsive building design. The climate data is useful not only for estimating heating- and cooling load of the building but also for creating passive design concepts. The environment potential discovered through survey and analysis of the climate information on sun, wind, humidity, air temperature provide necessary ideas to build a passive design strategy and demonstrate what kind of passive designs are effective at the specific site. They also demonstrate the capacity of renewable energy resources such as photovoltaic's, wind generation, geothermal and others that can replace conventional energy.

The climate data consists of three scales; macro-, meso- and micro climate data. Macro-climate data can be obtained from the nearest weather station but micro-climate data can often only be obtained by individual measurements at the site.

Special considerations are needed in an urban context, where heat island effects with increased temperature levels, limited access to solar radiation and pollution and noise from traffic and other activities are some of the special challenges to meet

What to built – Building brief

This phase includes definition of design goals, objectives and criteria as well as preliminary feasibility studies. In this phase, the building type and the proper size of the building are discussed, taking surrounding conditions into consideration.

Analysis of site potential including wind, sun and landscape, urban development plans, analysis of clients' profile and chart of functions create a roadmap of energy system principles, renewable energy systems, indoor environment and construction solutions. The outcome is an analysis of the context, site and building design potential and a road map of possible design strategies

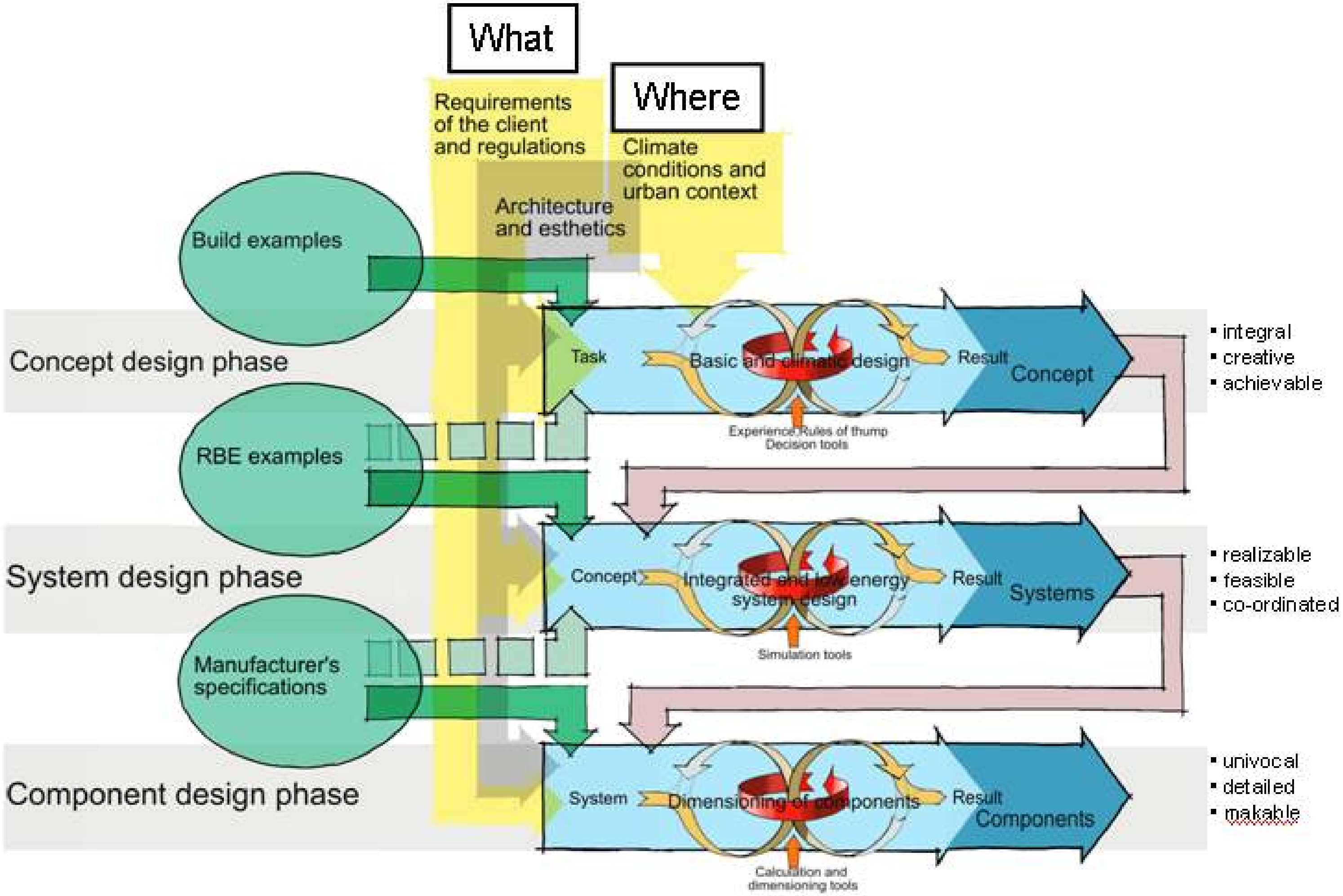


Fig. 2.6 Design Process of Responsive Building.

PHASE 2:

Development of design concept

As mentioned earlier, there exist various design alternatives and technological alternatives for the desired responsive building, even if each results in the same building performance, the same energy consumption or the same environmental impact. (See pattern A, B and C)

It is difficult in general to develop passive design strategies under the harsh environmental condition either in natural (physical) sense or social sense, so that pattern A may be compelled to take in that case.

Through the sketching process architectural ideas and concepts, functional demands as well as principles of construction are linked to energy and environmental building concepts and indoor environment through application of the design strategy presented in figure 13. Different conceptual design solutions are developed and their relative estimated merits are continuously evaluated, including architectural qualities, against the goals in the building design brief. The outcome is an integrated building concept.

The final decision will be made after extensive discussions among the client, the architect, the engineer and other stakeholders who possess different cultural and scientific background. It may depend on the following conditions:

1. Social- and physical environmental conditions of building surroundings
2. Building type and its operating (management) system
3. Lifestyle of the occupants
4. The type of CI (Corporate Identity) or CSR(Corporate Social Responsibility) concerning environmental principles of the company
5. Private preference or a sense of values (environmental ethics?) of the client
6. Aesthetics

PHASE 3:

System design and preliminary performance evaluation

In the system design phase the building concept develops into specific architectural and technical solutions and systems through sketches, more calculations and adjustments. Architectural, space and functional qualities, the construction and demands for energy consumption and indoor environment converge in this phase.

In this phase, the basic building form and its site location are determined after a series of functional analysis (design strategy step 1). At the same time by applying step 2-4 in the design strategy in figure 2.4, a frame of responsive design is built considering various ideas of integration of passive- and active systems as reflected in the design concept explicitly with consideration of RBEs and renewable energy technologies.

After the system design is completed, the performance of the building should be inspected. There are many indicators of building performance such as energy consumption for HVAC and lighting system, CO_2 emission, room air temperature fluctuation with/without HVAC systems, et cetera.

Design optimization persists until the design goals and objectives are met. The two ways to predict and evaluate building performance on this phase are as following;

1) use of design guideline
2) use of design tools (simulation tools)

Using design guidelines is a more simplified method for designers to evaluate building performance in the early system design phase. The guidelines are usually based on raw data from many parametric studies conducted by computer simulation. A good example of such guidelines is the LEHVE design tool for residences in Japan described in chapter 4.

If the performance of the system design is not satisfactory, the design should be modified and often goes back to the design drawing board.

Later in the system design phase design tools (simulations tools) can be used to evaluate the performance. Today, many kinds of design tools have been developed and aid one in determining building performance quantitatively. However the evaluation of total performance can be complex when plural RBEs and renewable energy technologies are integrated into one building, because most design tools are developed to evaluate a building that has a single RBE system. Some design tools are demonstrated and introduced in chapter 4.

PHASE 4:

Component design

In this phase after the performance of system design is confirmed, the final design will be completed. Here technical solutions are refined and design documents are created including final drawings and specifications in cooperation with building companies, suppliers and product manufacturers. The outcome is a comprehensive description of the entire project.

The buildings improve for several reasons;

1) Less expensive due to reduced mechanical equipment and energy needs.
2) More comfortable due to decreased load of mechanical equipment
3) More responsive to the needs of the occupant due to customizable environment.

PHASE 5:

Operation and management

Many energy problems can be traced to a conflict between building services and many conflicts between services are control issues. An energy efficient design strategy should overcome this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward. It is not good policy to expect the control system to resolve conflicts.

2.4 Design Process Case Study: Dutch Embassy in Canberra, Australia

In order to illustrate the Annex 44 integrated design process the newly built chancellery of the Dutch embassy in Canberra, Australia is used as a case study.

The current chancellery is a curved two-storey building from the 1950's built according to traditional Dutch style (e.g. brickwork). It is situated in a 7800 m2 green area in the embassy district.

Figure 2.7. Current chancellery of Dutch Embassy in Canberra, Australia [photo credit: Dutch Ministry of Foreign Affairs]

The existing chancellery of the Dutch embassy in Canberra, Australia does not meet today's standards on functionality, comfort and sustainability. After a study into the possibility of renovation, it was decided to design a newly built. The newly-built is a round two-storey pavilion with a centrally placed atrium that connects all other surrounding spaces.

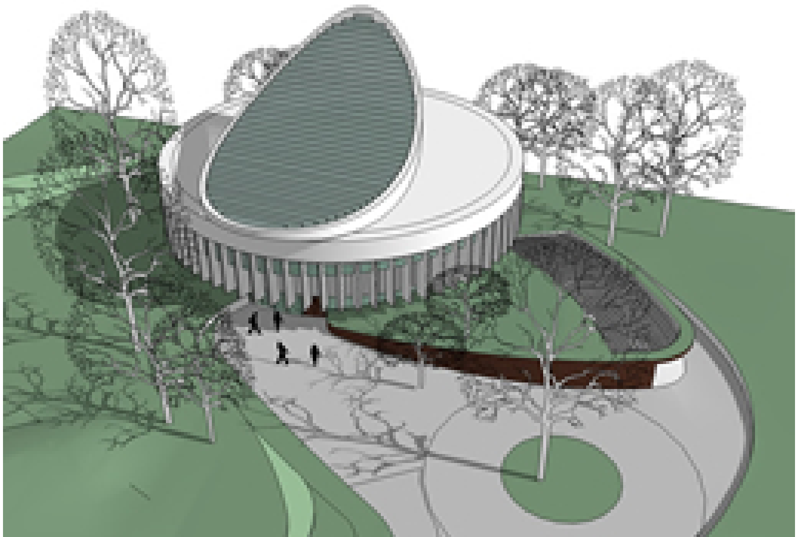


Figure 2.8. Conceptual design of Dutch Embassy in Canberra, Australia [illustration credit: Rudy Uytenhaak Architects]

PHASE 1

Where to built - Building location

Knowledge of climate characteristics of the building site is essential in order to define the starting points in the design of responsive building concepts. Notion of these characteristics provide insight into the potential energy flows that can be harvested on-site and therefore the possible effective (passive) design solutions.

The following parameters are relevant in a climatic context:

- General climate
- Ambient temperature
- Humidity
- Sun path and radiation levels
- Wind patterns
- Precipitation and evaporation
- Soil and vegetation
- Urban context

Canberra is located in the south western part of Australia and has a relatively dry, continental climate with warm to hot summers and cool to cold winters. In January, the warmest period of summer, the average daily extremes in temperature are 13.0 ˚C is 27.7 ˚C. July, the coldest period in winter, has average daily extremes of 11.2 ˚C and -0.2 ˚C. Because of its inland location, relative humidity in Canberra is quite low at around 37-40% in summer (at 3pm).

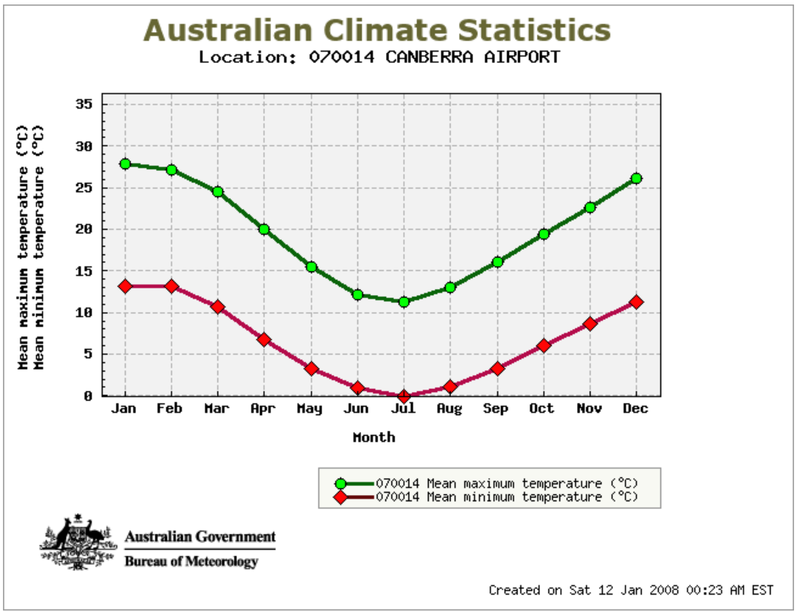


Figure 2.9. Average minimum and maximum temperatures throughout the year

While Australia is located at the southern hemisphere, the sun travels from east to west and peaks out in the north. Canberra is very sunny. On average there is 7.6 hours sunshine per day, ranging from 5 to 6 hours in winter to 9 hours in summer. The average solar radiation is 17.5 MJ/m^2, ranging from 8.2

MJ/m^2 in June to 26.4 MJ/m^2 in January. The highest solar altitude of 79 ° is reached in Australian summer and the lowest solar altitude of 32 ° is reached in winter (see sun path diagram).

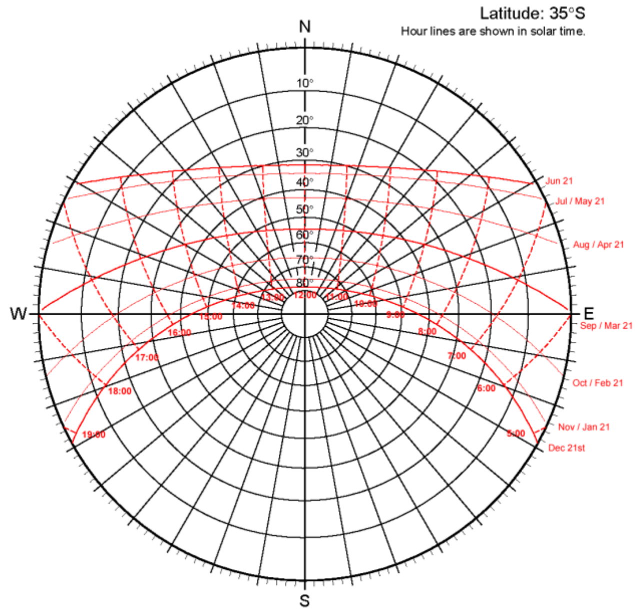


Figure 2.10 Stereographic sun-path diagram Canberra (35 S) [source: www.luxal.eu]

Canberra is not very windy. The prevailing wind direction is northwest. During the summer period, western and eastern winds occur during reasonable parts of the day. The north western and western winds carry dry hot desert air along in summer and cold air during the winter and night-time.

The average annual rainfall is 629 mm with an average of 108 rain days a year. The rainfall is evenly distributed throughout the year with 65.3 mm in October and 39.6 mm in June. Rainfall varies throughout the area around Canberra. The area to the west receives much more rainfall. Average annual evaporation in Canberra is 1677 mm, however this can range from around 8 mm/day in summer to as low as 1-2 mm/day in winter.

The thin top layer of the Canberra soil consists of coarse grained sand. Below 15 to 30 cm the soil becomes more clayish. This type of soil can easily erode on sloped land. The urban area of Canberra is stripped from its natural vegetation, but to the mountains in the southwest most of it still exists.

The embassy grounds measure 7800 m^2 which houses the current chancellery and the private house of the ambassador. The chancellery is situated in a green area which contains many trees.

Considerations for the building design

- Canberra has relatively warm summers and cool summers. The relatively large diurnal and seasonal variations in temperature allow for passive cooling techniques such as night-time ventilation and earth coupling.
- The air in Canberra is relatively dry. Therefore, the design should take humidity control into account. Preferably from passive means such as water bodies, vegetation or from air cooling through embedded ducts.

- The high air temperatures in summer call for measures to reject all solar radiation from entering the building during the times the building is occupied. On the contrary, during the winter all solar radiation is welcome. In spring and autumn solar radiation from certain sun angles are undesired.
- Daylight control is necessary throughout all times of the year to prevent hindrance.
- Prevent the negative effects from the north western winds by either adverting the wind flows or preliminary treatment.
- The temperate eastern winds are welcome.
- Use a rainwater catchment and storage system for flushing toilets and include water-saving measures throughout the building.
- Careful consideration of terrain and vegetation is necessary in order to prevent soil erosion.

What to built – building brief

This stage includes definition of design goals, objectives and criteria as well as preliminary feasibility studies. In this phase, the building type and the proper size of the building are discussed, taking surrounding conditions into consideration.

Analysis of site potential including wind, sun and landscape, urban development plans, analysis of clients profile and chart of functions create a roadmap for the indoor environment, energy system principles, renewable energy systems and structural solutions.

The following parameters are relevant in this context:

- Spatial requirements
- Sustainability requirements
- Functional requirements

Spatial requirements

- Embassy building which can employ 20 people.
- The building includes 800 m2 of office and meeting spaces.
- Allow for the future possibility to combine another department from Sydney.

Sustainability requirements

- Added focus on sustainability.
- High priority on the preservation of existing trees.

Functional requirements

- Industrial, Flexible and Demountable (IFD) construction techniques with a light footprint.

PHASE 2:

Development of design concept

The concept development is a creative process that embraces two complementary objectives. First is to design in such a way that energy requirements are kept as low as possible. This includes careful selection of orientation, building form and layout and is succeeded by the selection of building components, elements and materials. Preferably building components and elements are designed in such a way that they contribute to an increased energy performance of the whole building. Therefore components and elements should not be designed to meet structural, functional and architectural requirements only, but also with the aim to gain in energy-efficiency (as part of improved overall sustainability). The challenge here is to exploit synergetic effects and overcome conflicts through creative solutions. Second is to design complementary sustainable comfort systems to meet final demands. Such systems preferably run on energy from renewable sources or otherwise form efficient use of non-renewable energy sources.

Different conceptual design solutions are developed and their relative estimated merits are continuously evaluated, including architectural qualities, against the goals in the building design brief. The outcome is an integrated building concept. The final decision will be made after extensive discussions among the client, the architect, the engineer and other stakeholders who possess different cultural and scientific background. Decision-making may depend on the following conditions:

- Social- and physical environmental conditions of building surroundings
- Building type and its operating (management) system
- Lifestyle of the occupants
- The type of CI (Corporate Identity) or CSR(Corporate Social Responsibility) concerning environmental principles of the company
- Private preference or a sense of values (environmental ethics?) of the client
- Aesthetics

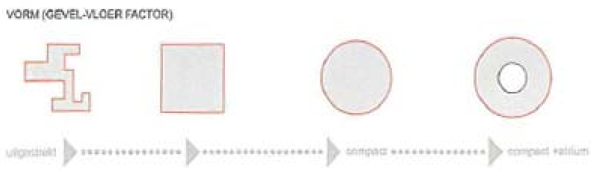
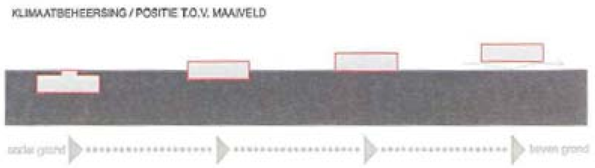
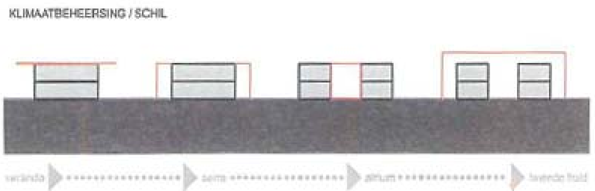
Sustainability as a design context

Sustainability knows many facets. The key to a sustainable building design is to find equilibrium between different quality aspects of the process of building design and construction. Quality aspects include the following: social, technical, policy, ecological, spatial and economical.

As a starting point two principles are taken for the initial design concept: an ‘installation-less building’ with indoor conditions that maintain ‘forever spring’. This resulted in a compact building with atrium. The atrium is the central place of the building which functions as the main component for indoor climate control. The neighbouring zones are kept comfortable from their connection to the atrium. To ensure comfortable temperatures and daylight levels throughout the seasons, the roof of the atrium is provided with a single mechanism that controls the amount of solar radiation to suffice the needs. The decisions led to this concept are explained below.

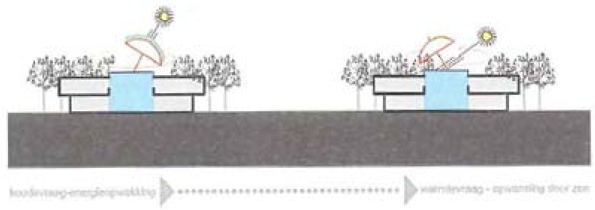
Heating and cooling strategy

Initial conceptual design studies include the impact of some relevant design parameters on the heating and cooling strategy; building shape, position of building volume with respect to the surface grade and the conceptual envelope design. The following figures show the different options that were considered.

	**Compactness of the building layout** Compact building design minimises facade area in relation to a given volume and therefore it minimises initial heat losses. However, when compact volumes get too large the innermost areas become cut off from the outdoor environment. This can be solved by the inclusion of an atrium.
	**Position of building volume with respect to surface grade** The earth's large thermal storage capacity can be used for tempering large daily and seasonal variations in the climate. The building volume can be fully or partly buried. Alternatively the building volume can be elevated to allow passive cooling from air flows.
	**Conceptual envelope design** The building's envelope is the primary intermediairy between the indoor environment and outdoor conditions. Different strategies of envelope design set initial heating and cooling demand of the building.

Sunshade / parasol concept

In order to maintain spring conditions the architect proposed a rooftop mechanism that functions as a parasol. It shades the atrium from the sun to prevent overheating and can be turned away in cold periods to enable passive heating strategies.

	**Parasol** The concept of the parasol functions as a sun shading device during the warmer periods and allows solar radiation to enter the building in colder periods.

PHASE 3:

System design (and preliminary performance evaluation)

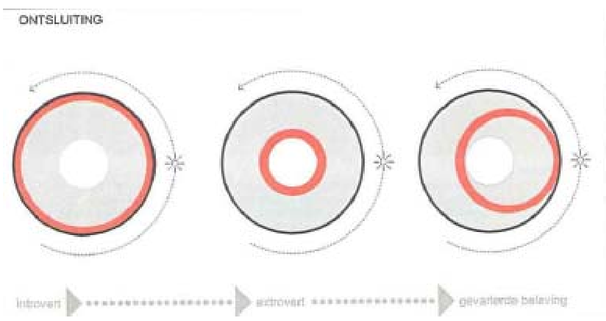
In the system design phase the building concept develops into more specific architectural and technical solutions. All architectural, spatial, functional, structural and ecological qualities converge in this phase.

Basic building form and site location are determined and decisions are made from a collection of considered design options on integration of passive- and active systems, responsive building elements and renewable energy technologies.

After completion of the system design, building performance should be inspected in order to validate the decisions made. There are many indicators of building performance such as energy consumption for mechanical building services, CO2 emission and zone air temperature fluctuation. Design optimization persists until the design goals and objectives are met. As long as the performance of the system design is not satisfactory, the design should be modified by reconsidering all design decisions made earlier and from alternative design options.

Zoning

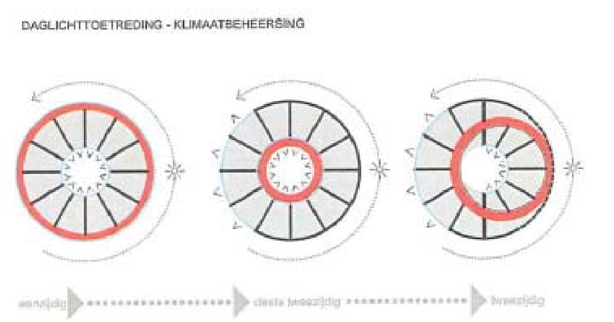
Through zoning, different spaces with identical comfort needs are grouped and placed within the building layout according to energy offer from the local climate. For example, zones that require heating are orientated towards the sun. Zones that have less stringent comfort demands (e.g. corridors, technical rooms, storage space, etc.) can be used as buffer spaces between habitable rooms and the outdoors. By choosing an optimal arrangement of different zones, significant energy reduction can be achieved.

	**Internal accessibility** The corridor can be placed on the inside or on the outside of the perimeter of the building. An alternative is the placement of the corridor towards the sun in order to use the corridor as a buffer space. By doing so the habitable rooms are not experience increased direct solar

	radiation levels during the middle of the day.

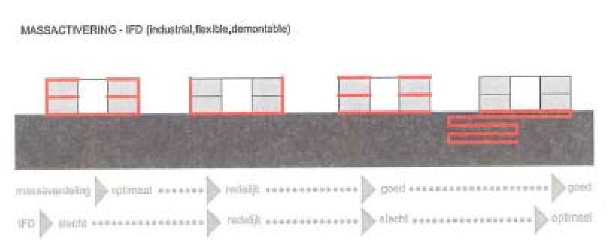
Daylight admission

Energy performance estimations on the preliminary design concept showed significant energy demands for lighting. Therefore it was decided to optimise the use of natural light to minimise the needs for artificial lighting. In conformity with the zoning discussed earlier, a strategy for daylight admission can benefit from the same concept.

	**Daylight admission** The presence of the atrium and the use of the corridor as a buffer space still allow sufficient illumination from natural light.

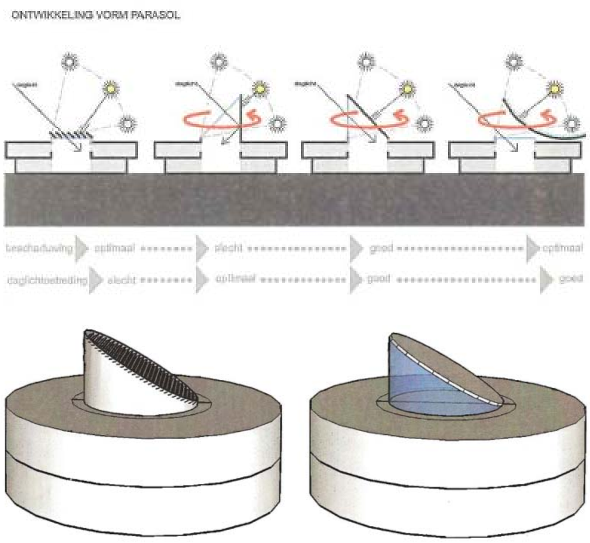
Thermal mass vs. IFD

Massive building elements (e.g. stone, concrete) have the capacity to store large amounts of thermal energy; tempering fluctuations in temperature. On the contrary, massive buildings are less flexible to adjustments and require more effort during the demolition phase. This is in conflict with the requirement from the client to implement the (IFD) building concept. IFD stands for Industrial, Flexible and Demountable and integrates economical issues with sustainability.

	**Thermal mass vs. IFD** The use of massive building elements is not in accordance with the IFD building concept. Alternatively, the earth's thermal storage capacity can be used as a substitute to massive building elements. The building construction can be lightweight and therefore answers to the concept of IFD.

Parasol development

Besides controlling comfortable amounts of solar radiation, the parasol has a second function of allowing comfortable amounts of daylight to enter the building. A movable element on top of the atrium is able to change its orientation in order to shade the atrium when needed without interfering with sufficient illumination from natural light.

	**Parasol development** Shading and daylight entry behaviour of different configurations of the parasol design have been studied. Design options include parasol movability (fixation or rotation), parasol edge transparency (transparent or opaque) and parasol hood finish (opaque or louvered).

Additional sun shading

The upper floor hangs over the ground floor and by doing so it provides additional shading to the ground floor.

The parasol on top of the atrium protects the building from intense solar radiation. At times the intensity of the sun is too great an additional textile sunshade placed on the inside of the atrium is available. The sunshade can be altered and behaves like a diaphragm. In fully closed state it also acts as an additional layer of insulation.

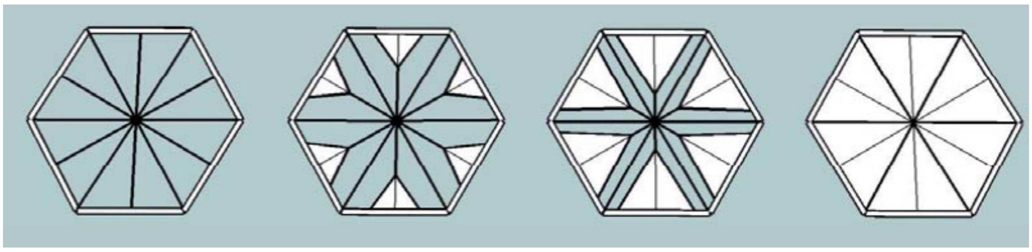


Figure 2.10. A textile sunshade mounted on the inside of the roof of the atrium provides additional shading, if necessary [illustration credit: Rudy Uytenhaak Architects]

PHASE 4:

Component design

When the performance of system design is confirmed, the final design will be completed. Technical solutions are refined and design documents are created, including final drawings and specifications in cooperation with building companies, suppliers and product manufacturers. The outcome is a comprehensive description of the entire project.

Shape of parasol

The final concept of the parasol is a rotating shading device that can alter its position with respect to shading needs without obstructing admission of sufficient daylight. The shading louvers block high sun angles in the summer period but allow some penetration from lower sun angles in winter.

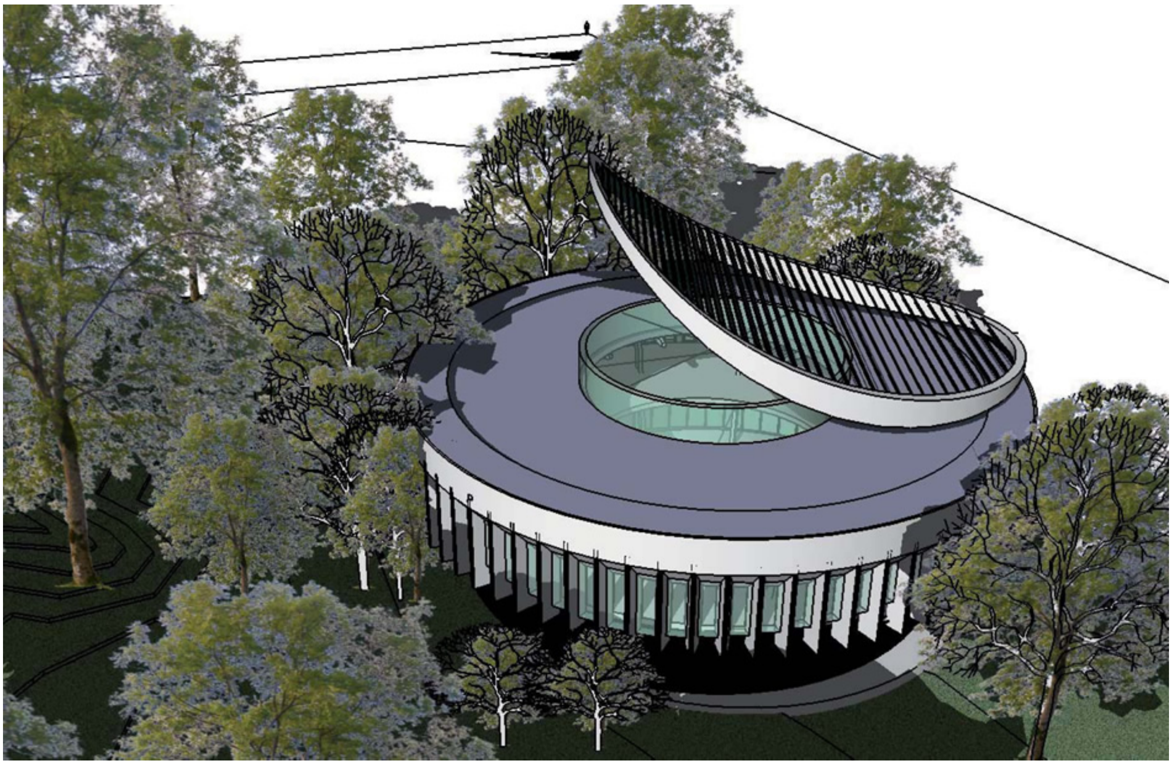


Figure 2.11. Definitive shape of the rotating parasol on top of the embassy building [illustration credit: Rudy Uytenhaak Architects]

PV-cells on parasol

The shading elements from the parasol are covered with photovoltaics which generate the electricity for moving the parasol to any desired position. Surplus electricity generation is passed to the building's electricity grid.

Daylight control

Both floors have a variable window height over the perimeter of the building. Small windows on the eastern and western side of the building minimise negative impact of low sun angles and large windows on the northern and southern side allow natural light to enter the rooms behind.

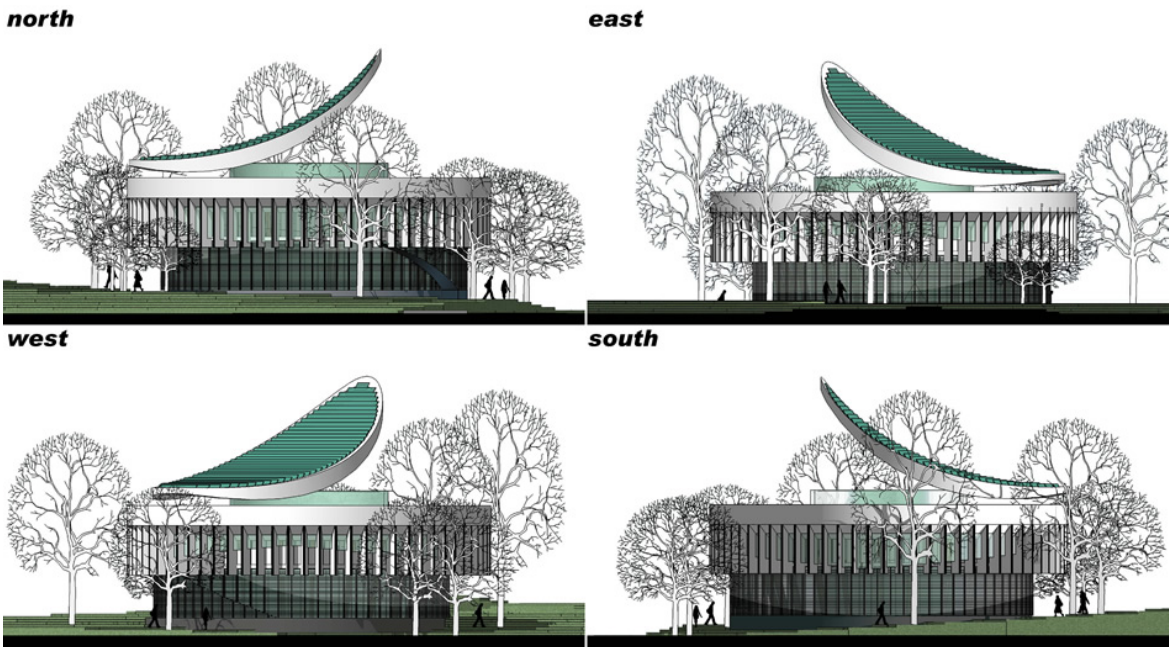


Figure 2.12. Variable window height over the perimeter of the building [illustration credit: Rudy Uytenhaak Architects]

Ventilation system

A circular ventilation tube is wrapped around the building, placed in the foundation. Fresh air is directly drawn in from outside or is preconditioned through a series of embedded ducts. The first floor is supplied with fresh air with aid of small ducts that run upwards along the columns. Exhaust air is withdrawn from the building through openings at the top of the atrium.

Grey water system

A rainwater collection unit on the roof is connected to the building's grey water system. Filtered water is foremost used for gardening (complemented with rainwater collection at the garden). Abundant water can be used for flushing the toilets as well.

Space heating and cooling

Space heating and cooling is derived from a radiant surface floor heating system with low temperature heating and high temperature cooling. Tubes are integrated into a thin covering floor made of concrete. The system is complemented with a ground-source heat pump with seasonal storage ability.

Construction

The basis of the construction was the application of sustainable building materials which could be re-used in case of demolition and the incorporation of a high degree of (spatial) flexibility. This is achieved by minimising the amount of columns in the spatial plan.

The main structural concept consists of laminated wooden columns with complementing coupling rods made of steel. The prefabricated wooden boxed floors contribute to the structural stability. The circular beam is also made of laminated wood.

Laminated wood is locally available and has advantages when it comes to re-use. The use of steel is avoided except when their structural properties are beneficial. This is the case with rods that carry tensile loads. Made from steel they can be designed much slimmer than elements made of wood.

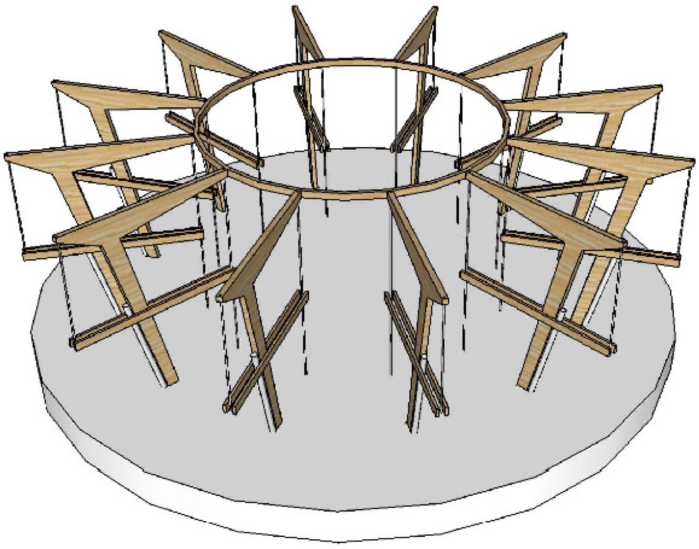


Figure 2.13. Laminated wooden elements form the main structural concept [illustration credit: Rudy Uytenhaak Architects]

Situation

The building is placed within the existing tree plan south of the current chancellery. The existing trees provide additional shading in summer. Furthermore, the existing access roads and entrance gate remain in service. A small newly paved area ensures accessibility of the newly built chancellery.

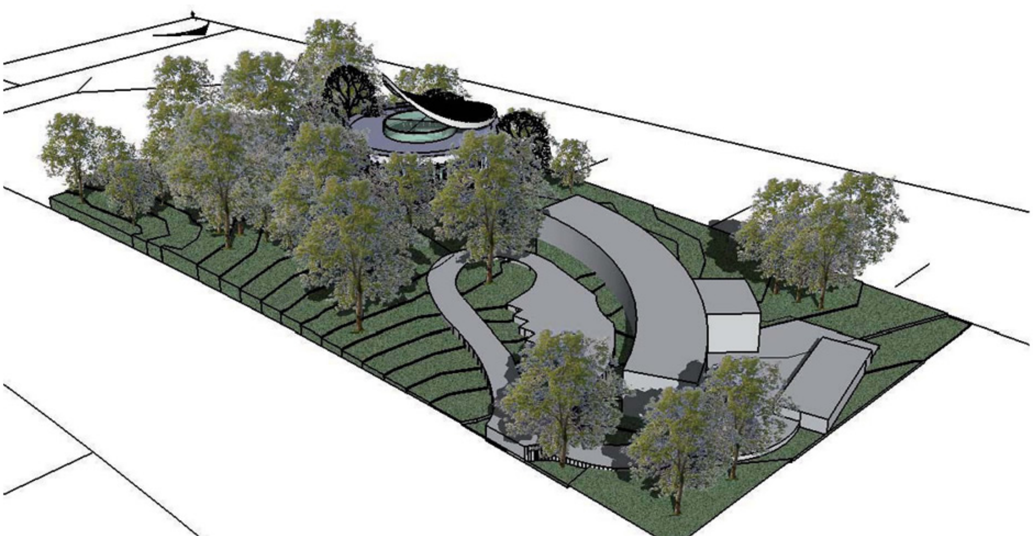


Figure 2.14 Placement of new chancellery within the existing situation [illustration credit: Rudy Uytenhaak Architects]

PHASE 5:

Operation and management

Many energy problems can be traced to a conflict between building services and many conflicts between services are control issues. An energy efficient design strategy should overcome this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward. It is not good policy to expect the control system to resolve conflicts.

References

Van den Dobbelsteen, A.A.J.F. (2008) Nota van Uitgangspunten voor de nieuwe Nederlandse ambassade in Canberra – bioklimatische randvoorwaarden en ideeën voor het ontwerp van de nieuwe kanselarij, Delft.

Rudy Uytenhaak Architectenbureau (2008) Concept preliminary design, Amsterdam.

Rudy Uytenhaak Architectenbureau (2008) Concept final design, Amsterdam.

Project and design team, internal communications.

3. Responsive Building Concepts

Environmental design and control of buildings can be divided into two very different approaches – the exclusive and the selective approach.

<u>In the exclusive approach</u> energy efficient building concepts are created by excluding the indoor environment from the outdoor environment through a very well insulated and air tight building construction and acceptable indoor environmental conditions are established by automatic control of efficient mechanical systems. The idea behind this approach is that the very fluctuating outdoor environment often disturbs the goal of a stable, comfortable indoor environment making it difficult to control with regard to both energy use and indoor climate, pattern A buildings in figure 3.1.

<u>In the selective approach</u> energy efficient building concepts are created by using the building form and envelope as a filter between the outdoor and the indoor environment maximising the benefits and human coexistence with nature and acceptable indoor environmental conditions are established by user control of building envelope and mechanical systems. The idea behind this approach is to make optimal use of the available environmental conditions, pattern B buildings in figure 3.1.

Pattern A

Energy Efficiency

Pattern B

Well - Being

Figure 3.1. Illustration of design approaches to energy efficient buildings.

In the selective approach it is important that the building is responsive to the fluctuations in the outdoor environment and the changing needs of the occupant s. This “responsive behavior” can be approached from a technological point of view and from an architectural point of view:

1. Responsive by exploiting the dynamic fluctuations of the environment to minimize the energy use of HVAC and lighting systems. (technological)
2. Responsive by exploiting the dynamic fluctuations of the environment to maximize the human coexistence with nature, to create higher productivity and a healthier, sensing and refreshing space, etc. (architectural)

In a responsive building concept an optimum must be found between the, sometimes contradictory requirements from energy use, health and comfort. From the viewpoint of human coexistence with nature the approach is to make buildings “open” to the environment and to avoid barriers between indoors and outdoors, while from the viewpoint of energy savings the approach for certain periods is to exclude the buildings from the environment. The transition between indoors and outdoors herewith becomes a more or less hybrid zone were the energy gains are not only rejected, but are stored, tempered, admitted or redirected, depending on the desired indoor conditions, see figure 3.2.

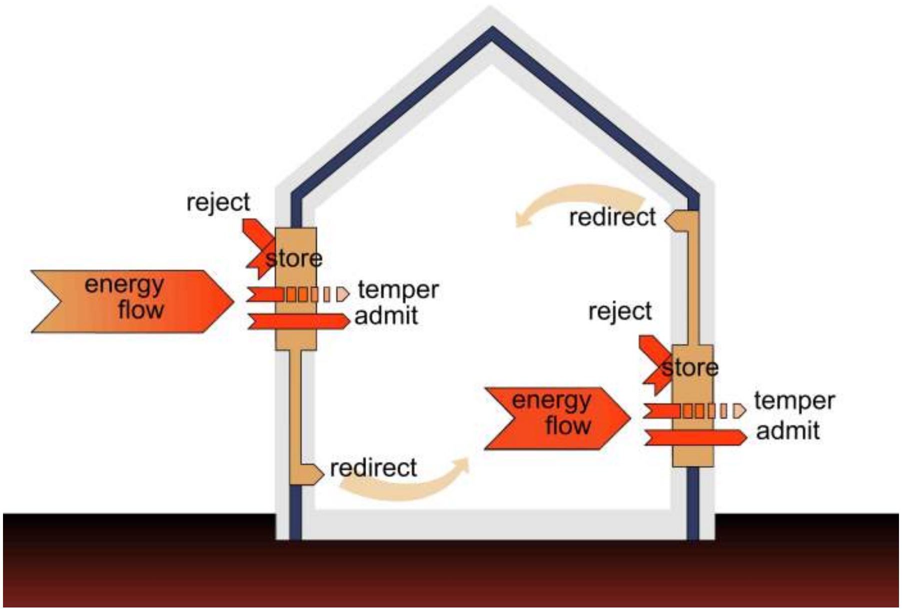


Figure 3.2. Illustration of the responsive capability of the building envelope.

Climatic design principles are essential to achieve an optimum responsive building concept. Climatic design is the art and science of using the beneficial elements of nature – sun, wind, earth and air temperature, plants and moisture – to create comfortable, energy-efficient and environmentally wise buildings. The desirable procedure is to work with, not against, the forces of nature and to make use of their potentialities to create better living conditions.

The principles of climatic design derive from the requirement for creating human comfort in buildings using the elements of the natural climate. Perfect balance between natural resources and comfort requirements can rarely be achieved, except under exceptional environmental circumstances, and the climatic design will vary throughout the year depending upon whether the prevailing climatic condition is “underheated” compared to what is required for comfort (i.e., as in winter) or “overheated” (i.e., as in summer).

In this respect responsive building elements are essential technologies for the exploitation of the environmental and renewable energy resources and in the development of responsive building concepts the challenge is to achieve an optimum combination of responsive building elements and integration of these with the building services systems and renewable energy systems to reach an optimal environmental performance.

Nowadays we have access to advanced and improved building materials, but above all, are able to measure and control the performance of buildings, building services and energy systems with an advanced building management systems (BEMS). These BEMS offer buildings and building components “intelligence”. Based on changing indoor or outdoor conditions responsive building elements can be directed by the BEMS to change there physical performance. This opens a new world of opportunities. Buildings no longer act as ridged objects that need a large heating installation in winter and big cooling equipment during summer to “correct” the indoor climate, but buildings become an additional “living” skin around occupants, keeping them in contact with nature, but at the same time protected when necessary.

In Annex 44 an Responsive Building Concept is defined as:

“An integrated design solutions where responsive building elements, building services systems and energy-systems are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality”.

3.1 Classification of Responsive Building Concepts

In the development of existing energy efficient building concepts the main focus has typically been on application of only a few of the available technical solutions. Examples are:

- The “Passive House” concept which mainly focuses on super insulated and air tight envelopes combined with high efficiency heat recovery and passive solar heating.
- The “Solar House” concept which mainly focuses on utilization of renewable energy technologies such as passive and active solar heating and solar cells
- The “Smart House” concept which mainly focuses on advanced solutions for demand control and efficient control of fossil fuel technologies
- The “Adaptive Building” concept in which building elements actively respond to changing climate conditions and indoor environmental conditions as required by the occupants

These concepts are clearly the result of a sub-optimization by an expert in either building physics, renewable energy or control engineering.

The Responsive Building Concepts developed within Annex 44 can be considered as design solutions which are optimum combinations of the existing concepts by integration of the full range of technical solutions into one system. The main difference between responsive building concepts and other energy-efficient building concepts is the application of responsive building elements and their integration with building services systems and energy systems.

The purpose of classification of Responsive Building Concepts is to define/specify the concept according the most important issues. In Annex 44 a “Responsive Building Concept” is classified according to the following categories and parameters:

TABLE 3.1. Categories and parameters for classification of Responsive Building Concepts

Category	Parameter
Climate	Cold, moderate, warm, hot-dry, hot humid, …
Context	Urban, suburban, rural
Building use	Office, school, residential, ...
Building type	High-rise, low-rise, row-houses, single houses, multifamily buildings, ...
Design approach	Selective, exclusive
Demand reduction strategies	Thermal insulation, air tightness, buffering, reduction of heat and contaminant loads, building form, zoning, demand control, efficient air distribution, solar shading, ..

Responsive building elements	Multifunctional facades, earth coupling, thermal mass activation, dynamic insulation, …
Building Services systems	Low temperature heating, high temperature cooling, low pressure mechanical ventilation, …..
Renewable energy technologies	Passive and active solar heating, wind, natural cooling, geothermal heat/cool, biomass, dayligthing, natural ventilation,..
Efficient energy conversion	CHP, HE gas boiler, heat pump, …
Control strategy	adaptive/rigid, user control/automatic

3.2 Description of Typical Strategies and Solutions

Typical strategies and solutions for responsive building concepts developed in Annex 44 are described in chapter 3.3. More detailed information can be found in Case study reports available from the Annex website. The main characteristics of the selected examples are given in table 3.2.

Demand Reduction Strategies. For all examples it can be seen that climatic design and demand reduction strategies are a very important part of all concepts. In colder climates the main focus is on high thermal insulation, high airtightness, high heat recovery of ventilation air and demand control while in warmer climates the main focus is on solar shading, facade design, passive cooling and dayligting.

Responsive Building Elements. With regard to the application of responsive building elements is seems that thermal mass activation (by natural night ventilation in colder climates and ground coupling in warmer climates) is a key technology for all climates and building types while other responsive elements are applicable only for certain climates and/or building types.

Low Exergy Building Services Systems. In order to optimise the use of renewable energy sources and improve heat pump performance floor (and wall) heating and cooling is used in many buildings. Secondly low pressure ventilation with very efficient heat recovery is used.

Renewable Energy Technologies. Typical technologies used include active solar thermal systems for domestic hot water (and heating), photo voltaic for electricity production and different systems for earth coupling either water based (deep sonds, energy piles) or air based (underground culverts).

Efficient Energy Conversion. In order to achieve high efficiency the systems often include heat pumps, high efficiency fans and heat recovery systems.

TABLE 3.2. Main characteristics of described Responsive Building Concepts.

Category	Building name						
	ChristophorusHaus Austria	Office Bregenz Austria	Nydalspynten Norway	Kaswoningen The Netherlands	WelWonen The Netherlands	Mabuchi Motor Headquarters Japan	Kansai Electric Power Co. Japan
Climate	Moderate	Moderate	Cold	Moderate	Moderate	Hot Humid	Hot-humid
Context	Suburban	Suburban	Urban	Suburban	Suburban	Suburban	Urban
Building use	Office	Office	Office	Residential	Residential	Office	Office
Building type	Single building, low-rise (3 stories). New construction	Medium rise (7 stories). Retrofit	Low- rise (3 stories). New construction	Row houses, low rise (2-tories). New construction	Single house, low rise (2 stories). New construction	Low rise (4 stories). New construction	High rise (41 stories). New construction
Demand reduction strategies	Highly insulated, air tight, buffering, building form, optimized glazing, solar shading, demand controlled ventilation (CO_2), efficient heat recovery (80%),	Solar shading, demand controlled ventilation, energy efficient daylight controlled lighting	High insulation, airtight, optimized glazing area, type and solar shading, daylight utilization, demand control, thermal buffering,	Highly insulated, air tight, southwest orientation of glazing, thermal buffering, ventilation heat recovery (95%),	Relative airtight, minimum thermal bridges, efficient heat recovery (95%),	Thermal buffer zones, optimum façade design, natural ventilation in atrium	“Eco-frame” construction, bottom-up solar shading, daylighting,
Responsive building elements	Thermal mass activation (floors and walls) with natural night ventilation	Thermal mass activation with natural night ventilation	Ground coupled air intake (EAHE),thermal mass activation with natural night ventilation	Solar space, thermal mass activation, natural night ventilation	Concrete core activated floor elements,	Double skin façade, roof garden, thermal activation and energy storage in concrete slab	Thermal activation of concrete slab,
Low exergy building services systems	Floor and wall heating and cooling (20 ^oC < t_{flow} < 32 ^oC)		Preheating and cooling in underground culvert, low pressure displacement ventilation system	Floor heating system, natural ventilation in solar space, balanced mechanical ventilation with heat recovery	Floor and ceiling heating and cooling, balanced mechanical ventilation with heat recovery	Task-ambient air conditioning with underfloor air distribution	Task-ambient air conditioning with underfloor air distribution
Renewable energy technologies	Earth coupling with deep sonds. Active solar collector (5 m^2). PV (10kW $_{peak}$).	Ground water source, geothermal probe and cooling tower	Passive solar, Earth coupling, natural ventilation, solar thermal collector (45m2, 7 kWh/m^2a),	Passive solar gains, glasfacades, active solar collector, PV 12kW $_{peak}$,	Earth coupling with energy piles (heating and cooling)	Natural ventilation, Natural night cooling of floor slab	Natural ventilation, use of river water as source for heating and cooling

Efficient energy conversion	Earth coupled heat pump (COP 4,03 measured), high efficiency fans and heat recovery		Efficient biofuel boiler	Efficient gas boiler	Earth coupled heat pump (COP 5,4)	Ice storage, gas-fired absorption chiller and hot water unit	Ice storage system , rive water heat pump
Control strategy	Demand controlled ventilation (IAQ and temperature), automatic control of solar shading and artificial light		Demand control of ventilation lighting and heating, user control, automatic night cooling strategy			Demand control of air conditioning and lighting	Demand control of air conditioning and lighting
Energy performance	Heating: 20 kWh/m^2a Cooling: 6,4 kWh/m^2a Primary energy < 49 kWh/m^2a (calculated)	Heating: 180 kWh/m^2a Cooling: 19 kWh/m^2a	Heating: 26 kWh/m^2a Cooling: 0 kWh/m^2a	Heating: 18 kWh/m^2 a, free cooling, 50% less primary energy than standard	Heating: 38 kWh/m^2 a, free Cooling, primary energy: 101 kWh/m^2 a (35% less than standard)	Primary energy: 1657 MJ/m^2 a (16% less than standard)	Primary energy: 1546 MJ/m^2 a (28% less than standard)

3.3 Demonstration Examples of Responsive Building Concepts

This chapter includes a description of a number of demonstration examples of responsive building concepts. A summary of the achieved results and lessons learned are given in chapter 3.3.8.

3.3.1. CHH – ChristophorusHaus, AUSTRIA

General data

Name of building	CHH – ChristophorusHaus
Year of construction	2003
Building type	3 story office building and a basement, new construction
Building use	Office building including a café and loading/parking zone inside
Building area	Total=2,090 m^2, heated and cooled =1,215 m²
Building owner/	MIVA
Location/address	Stadl-Paura, Upper Austria, Austria
Geographic location	48° 05' 02" northern latitude 13° 51' 50" eastern longitude Sea level 370 m
Context	Country side

Architectural concept

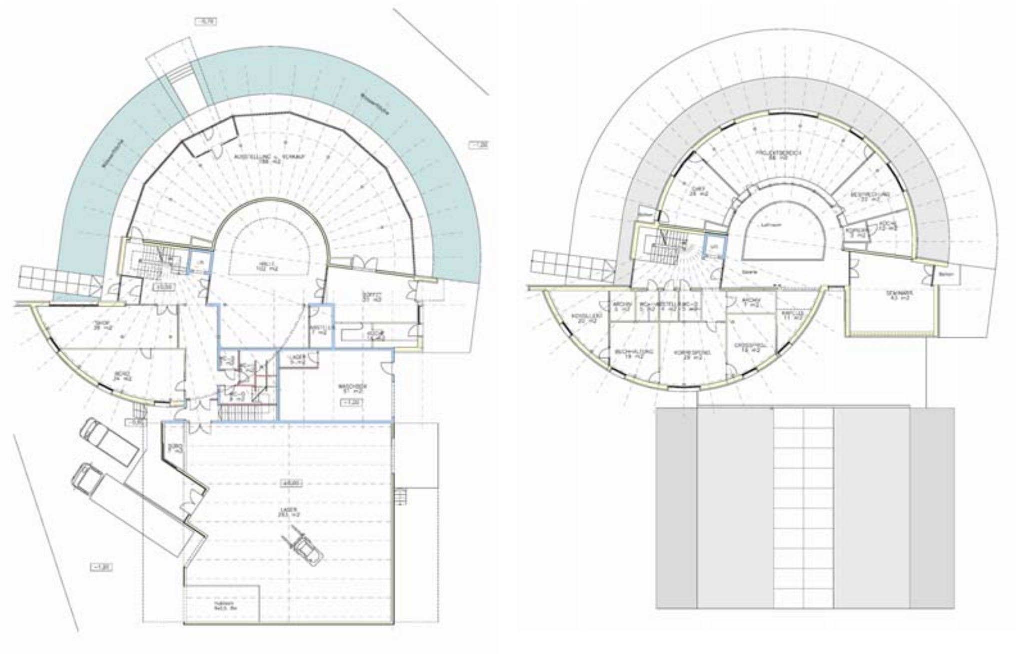


Figure 3.3: Architectural plan view of the office building, the ChristophorusHause" (left: ground floor, right: first and second floor, which are identical)

Design Approach

The initiative of the project was the building owner, who contacted a specialist who coordinated the entire planning process and carried out the energetic calculations and optimisations. It was shown that such coordination with one partner acting as "energy party in charge" was of great importance of such innovative construction project. This coordinator not only dealt with the conventional energy processes, but also kept the overview of the energy relevant areas and acted as the link between the project partners (building owner, architecture, planner, engineers engaged in statically calculations, constructional physicist etc.)

Demand Reduction Strategies

The building is highly insulated with Coefficients of heat transmission of: outside walls: U = 0.1 W/m²K; ceiling: U = 0.1 W/m²K; foundation: U = 0.1 W/m²K and glazed areas/atrium: U = 0.85 W/m²K. Thermal bridges has been avoided by insulating thermal weak points and using suitable constructions.

The building is very airtight with a measured value of: n50 = 0,41 h-1 and the ventilation system is equipped with high efficient heat recovery (circulating heat exchanger with up to 86% recovery rate).

The glazing areas have been optimized by dynamic building simulation and through application of external solar protection and heat protection glass. The solar shading is operated by sensors in the work area.

Responsive Building Elements

The following responsive building elements were used:

- Thermal mass: 100 tons were integrated by pavement, massive interior walls and staircase.
- Night Ventilation: The cooling concept is supported by a natural air flow through the atrium during the night

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Heating: Are realised through panels and floor heating, which are flown through with warm water (T_{flow} < 32°C) and integrated in the building components.

  Cooling: Are realised through panels, which are flown through with cold water (T_{flow} > 20°C) and integrated in the building components. It is thereby possible to have a cooling without the application of a compressor cooling machine. The cooling capacity of this concept is approximately 25 W/m².
- Ventilation: The ventilation of the office building is carried out with the means of two separated ventilation systems with heat recovery through a rotation heat exchanger.
  - Ventilation system for the office building area is with fresh air supply, heating and cooling. Nominal flow volume 2,800 m³/h, heat recovery rate 78%.
  - Ventilation system for the seminar rooms is with fresh air supply, heating and cooling. Nominal flow volume 1,000 m³/h, heat recovery rate 86%.

Renewable Energy Technologies

The following renewable energy technologies were used:

- Earth coupling with deep sonds: Water-circulated earth heat exchanger with deep sonds (8 x 100 m Duplex – Double-U-pipes DN 32) are used as heat source for a heat pump and for “direct cooling” in the summer period. Heat extracted from the ground in winter creates a beneficial temperature profile for the summer cooling period
- Photo Voltaic system: A PV system covers the yearly electricity demand of the heat pump, pumps and fans. 10 kW_{peak} peak load (from which 3.8 kW_{peak} was integrated in the facade and 6,2 kW_{peak} with an angle of 40° on the roof)
- Solar thermal system: A solar thermal system with a collector area of 5 m^2 supply the building with domestic hot water.

Efficient Energy Conversion

The following efficient energy conversion technologies were used:

- Heat pump: Powered by electricity and extracting heat from deep sonds, nominal power 43 kW at COP 4,03.
- Ventilation: High efficiency fans and high efficient heat recovery (circulating heat exchanger with up to 86% recovery rate).

Control Strategy

The following control strategies were used:

- Heating: Controlled by room thermostat, constant set point. The heating is deactivated on the weekends to enable a high efficiency of the system
- Cooling: Controlled by room thermostat by day and night ventilation strategy during night time
- Ventilation: In office spaces air flow rate is controlled by user profile. In conference rooms ventilation is controlled by CO_2 sensor and is activated when the CO_2 level is higher than a set value (1000 ppm). The ventilation is deactivated on the weekends to enable a high efficiency of the system.
- Lighting: The shading devices and the lighting is operated through sensors at the work area, which results in an optimal daylight utilisation.

Energy Performance

The performance of the building is reported to be:

- Heating demand: Predicted to be 14 kWh/m^{2}a (75% less than standard). The heating demand was measured to be 20 kWh/m^{2}a and the maximal heat load was 13 W/m^2 for the winter operation.
- Cooling demand: Predicted to be 7 kWh/m^{2}a (75% less than standard) The cooling demand was measured to be 6,4 kWh/m^{2}a and the maximal cooling load was 11 W/m^2 for the summer period.
- Primary energy demand: Predicted to be 49 kWh/m^{2}a (75% less than standard)
- Indoor environmental quality: The indoor temperature throughout the year remain on comfortable and constant levels, during winter 22–23°C and summer 23–26°C, although the outdoor temperature vary greatly. The same apply for the relative humidity, which lies rather steady between 30 and 40%.

The energy use is supervised via 24 hours running monitoring of all the systems. The person in charge of the operation on site is contacted, should there be a error message

Lessons learned

The operation of the building is of high satisfaction and the occupants are very pleased..

- to get an optimal daylight utilisation sensor controlled shading devices and lighting system are very efficient
- to get high air quality in the rooms a ventilation system controlled by CO_2 sensors is very useful
- for efficient energy supply ventilation and heating should be deactivated on weekends
- it is wise to monitor all the systems (24 hours a day), so that the person in charge of the operation on site can be contacted, if there is a error message
- monitoring of the whole energy system is very useful to find out if the design of the building and its energy supply worked well

The purpose of application of responsive building elements was to achieve low running costs and low environmental pollution by running the office building. Tthe performance improvement due to integration of RBE were:

- Lower energy demand (heating and cooling) because of using soil energy and activating thermal masses
- Improvement of the indoor comfort

The performance improvement of the integrated building concept was:

- 75% lower running costs compared with standard buildings
- More than 75% lower environment pollution compared with standard buildings
- Clearly higher indoor comfort

Cost aspects/affordability

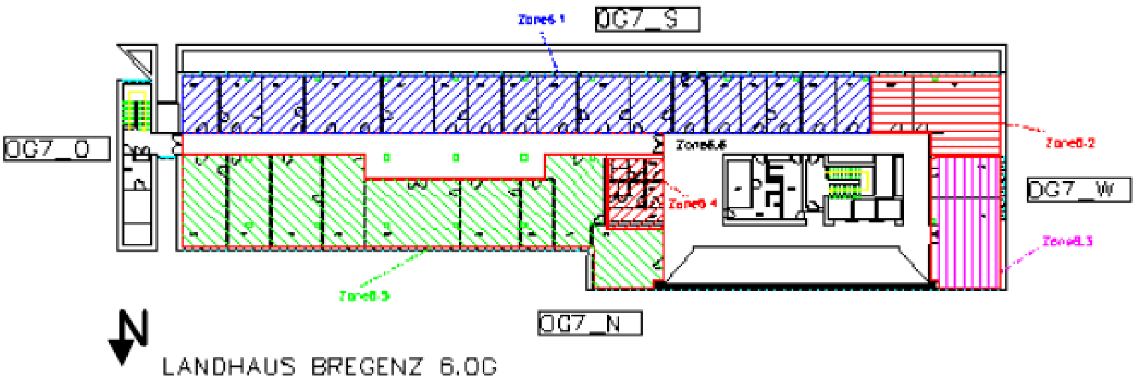
- The whole erection costs are about 10% higher than for standard buildings.

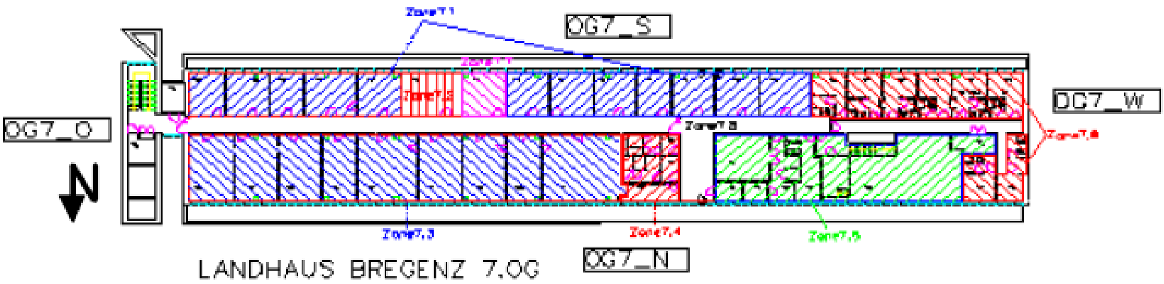
3.3.2 Building of the provincial government in Bregenz, AUSTRIA

General data

Name of building	Building of the provincial government in Bregenz	
Year of construction	1981	
Type of building	Retrofit office building, 2 basements ground floor, 7 upper floors,	
Use of building	Office building including a parking zone and a technical control room inside	
Heated/cooled building area	Total = 11,500 m^2, Heated/cooled = 10,000 m^2	
Building owner	Federal state of Vorarlberg	
Building leaser/tenants	Federal state of Vorarlberg	
Location/address	Bregenz, Vorarlberg, Austria	
Geographic location	47° 30' northern latitude 9° 46' eastern longitude	Sea level 450 m
Situated (city or country side)	Country side	

Architectural concept





Architectural plan view of the 6th and 7th floor of the building

Design Approach

The “Landhaus Bregenz” was built in the early eighties. The technical components like ventilation, heating and cooling system were up to standard of that decade.

To high room temperatures in summer are the main problems. Together with the proprietor's representative solutions to reduce the room temperature and the cooling demand has been elaborated. Architects, building physicists and structural engineers were not involved in this process

The main point of the study was to create an effective energy concept (EEC)

Demand Reduction Strategies

As the cooling is the main problem the demand reduction strategies are focusing on this.

Therefore, the building insulation level is not improved and the coefficients of heat transmission of: outside walls: U = 0.48 - 0,506 W/m²K; ceiling: U = 0.348 W/m²K; foundation: U = 0.341 - 582 W/m²K and glazed areas/atrium: U = 2.8 W/m²K are maintained.

The external heat load is reduced by application of control of the shading system and by demand control of the ventilation.

The internal heat load is reduced by changing the existing lighting devices to energy efficient lighting, by application of daylight controlled lighting and by substitution of the existing computer devices with energy efficient equipment

The cooling need is reduced by application of new thermal mass, by improved activation of the available thermal mass and by night ventilation.

Responsive Building Elements

The following responsive building elements were used:

- Thermal mass
- Night Ventilation

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Heating: Are realised through radiators

  Cooling: Are realised through split units in seminar rooms. These fan coils are controlled by a separate centralised air condition plant with a flow rate of 5,400 m^3/h. The rooms in the ground floor are supplied by 4 different air condition plants. The sum of the flow rates is 150,000 m^3/h. In each technical control room there is also a split unit

Renewable Energy Technologies

The following renewable energy technologies were used:

- Cooling sources were outdoor air at night, ground water, geothermal probe and cooling tower

Energy Performance

The performance of the building is reported to be:

- Heating demand: 180 kWh/m^2a.
- Cooling demand: 19 kWh/m^2a.
- Indoor environmental quality: The indoor temperature throughout the year remain on comfortable and constant levels, during winter 22–23°C and summer 23–26°C, although the outdoor temperature vary greatly. The same apply for the relative humidity, which lies rather steady between 30 and 40%.

Lessons learned

The main lessons learned were:

- People can work most efficient at a room temperature of 23°C. In case of rising temperature for example to 28°C the productive efficiency drops about 25 %.
- The steadily rising electric power consumption depends on two main aspects:
- The specific number of computer equipment per m² is rising.
- Split units have been used to air-condition different office areas.
- The main influence factor for high cooling loads is the solar radiation, followed by electrical appliances. The high cooling loads resulting from solar radiation often are home-made problems because of the ineffective shading systems (user profile, material, etc.)

The purpose of application of responsive building elements was to achieve low running costs and low environmental pollution by running the office building(only documented by simulation). The performance improvement due to integration of RBE were:

- Lower energy demand (cooling) because of using soil energy and activating thermal masses
- Improvement of the indoor comfort

The performance improvement of the integrated building concept was:

- By integrating measures for reducing the cooling demand the room temperatures can be reduced by 5 Kelvin compared with the actual situation without integrating a cooling system.

Cost aspects/affordability

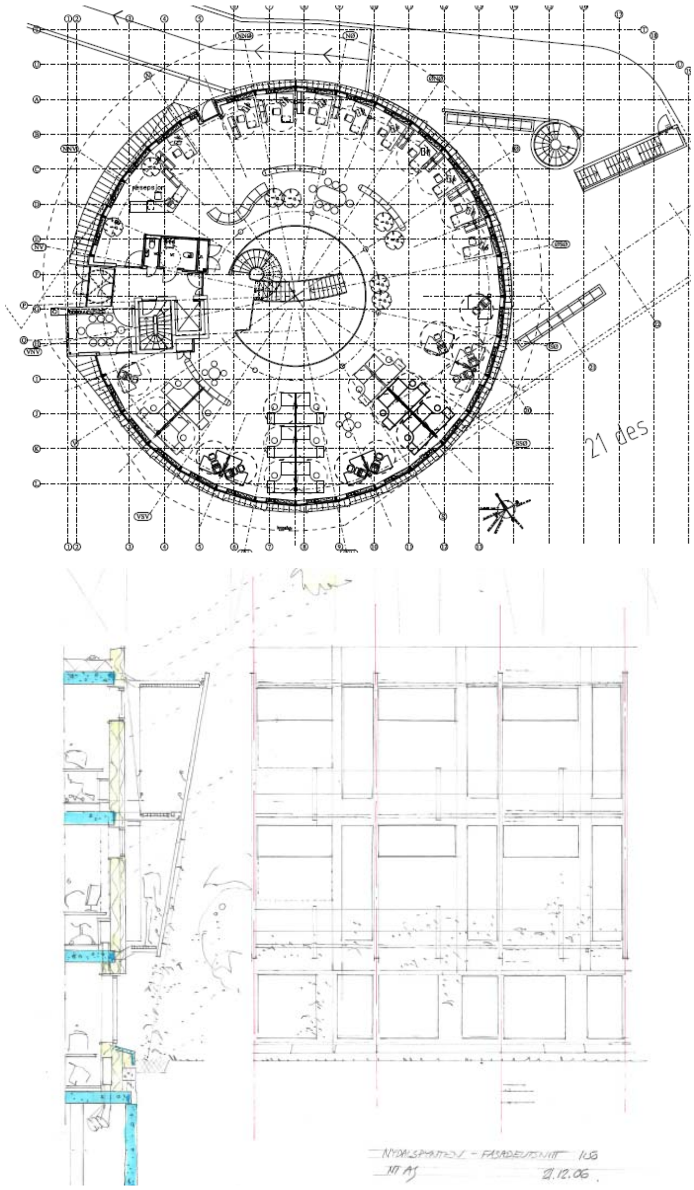
- The realization of a daylight controlled shading systems costs about 120 €/ m² office area. The costs for the modernization of the PC equipment and the lighting are between 80 and 100 € / m² office area.
- The investment costs for the passive cooling measures (NV, cooling tower + cooling panels) are about 50% lower than the investment costs for a chiller. The annual costs according VDI 2067 for sustainable cooling solutions are 50% to 80% lower than the annual costs of a conventional cooling system (e.g. chiller).

3.3.3 Nydalspynten, Norway

General data

<table>
<tr><td>Name of building</td><td colspan="2">Office building ‘Pynten’</td></tr>
<tr><td>Year of construction</td><td colspan="2">2008</td></tr>
<tr><td>Type of building</td><td colspan="2">New building</td></tr>
<tr><td>Type of construction</td><td colspan="2">3-storey (plus basement) building with atrium, (basement, ground floor, 2 upper floors)</td></tr>
<tr><td>Use of building</td><td colspan="2">Office building including parking zone underneath</td></tr>
<tr><td>Heated/cooled building area</td><td colspan="2">2484 m^2</td></tr>
<tr><td>Building owner</td><td colspan="2">Avantor ASA</td></tr>
<tr><td>Building leaser/tenants</td><td colspan="2"></td></tr>
<tr><td>Location/address</td><td colspan="2">Nydalspynten, Oslo, Norway</td></tr>
<tr><td>Geographic location</td><td>59°2 ' " northern latitude
10°5 ' " eastern longitude</td><td>Sea level m</td></tr>
<tr><td>Situated (city or country side)</td><td colspan="2">City</td></tr>
</table>

Architectural concept



Architectural plan view of ground floor and façade section

Design Approach

The objectives for the office building ”Pynten” were to achieve a building design with low energy consumption, with small environmental impact and good indoor climate. To achieve these objectives the project tries to exploit passive technologies which are natural ventilation, natural stratification, daylight, passive solar heating and passive cooling. The strategy that was followed was:

- a building integrated hybrid ventilation system with earth coupling (culvert solution),
- solid and indoor environment friendly materials,
- passive cooling (without cooling system),
- utilization of daylight,
- passive solar heating in the atrium

- together with optimal demand control of ventilation, lighting and heating.

The objectives were also to apply solutions with good user control, high robustness, little maintenance and long lifetime.

Demand Reduction Strategies

The building is highly insulated with coefficients of heat transmission of: outside walls: U = 0.22 W/m²K; ceiling: U = 0.15 W/m²K; foundation: U = 0.15 W/m²K and glazed areas/atrium: U = 1.1 W/m²K (average). Thermal bridges have been avoided by insulating thermal weak points and using suitable constructions. The balcony around the building is built in light materials (metal and wood) and strictly decoupled from the concrete slab and filled with 70mm isolation (λ = 0.036 W/m²K). This reduced the thermal bridges to 0.03 – 0.05 W/(mK) (from 0.18 W/(mK) for normal solution).

The building is very airtight with a value of: n50 = 0,6 h-1 and the ventilation system is equipped with efficient heat recovery with about 60% recovery rate. The ventilation air intake is provided through an underground culvert for preheating and precooling of outside air

The glazing areas have been optimized by dynamic building simulation and through application of solar protection and heat protection glass.

Each façade module has a width of 2.4m. Windows solution is 1.7m high and 2.0m wide. Frames have been calculated as 23% of windows area. The most effective way to reduce high solar heat gains in the offices with east, south, and west orientation are external shading devices. This has not been accepted due to architectonic reasons. Instead, solar protective glazing (g-value = 0,5) with internal shading devices was used.

The thermal mass of the building construction are fully exposed as suspended ceilings are not used and the floor only have a thin floor covering.

Responsive Building Elements

The following responsive building elements were used:

- Ground coupled ventilation (concrete culvert for preheating, precooling and sediments filtering of ventilation air
- Exposed thermal mass: In warm periods the pre-cooling in the culvert is not sufficient. Exposed thermal mass in the ceiling store heat during the day and release it during the night.
- Natural night ventilation: The cooling concept is supported by a natural air flow during the night)

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Heating: Are realised through electric heating panels placed under the windows.

Cooling: Are realised by pre-cooling in concrete culvert of ventilation air during the summer. Fresh air through the culvert (with temperatures between 16 and 19 C) is also used for night cooling. Therefore, no chillers are needed (although fan coils had to be installed locally for the data center).

- Ventilation: The ventilation system is a building integrated low pressure system with strict demand control and preheating in earth coupled system. It uses displacement ventilation for higher ventilation efficiency.

Renewable Energy Technologies

The following renewable energy technologies were used:

- Earth coupling through concrete culvert: 30m long culvert with 2 m height and 2.5 m width delivers 11.3 kW cooling power and 4 kW heat power
- Passive solar heating: Obtained especially in central atrium through optimization of the glazing area (by dynamic building simulation), application of solar protection and heat protection glass.
- Solar thermal system: A solar thermal system with a collector area of 45 m^2 supply the building with domestic hot water. The system delivers 17 000 kWh/a (7 kWh/(m^2a)).

Control Strategy

The following control strategies were used:

- Heating: Thermostat controlled electric heating panels coupled to a building management system (BMS) to ensure integration with ventilation, cooling and lighting. A thermostat, a motion sensor and a timer is used to control the heating system

Modus	Control	Proposed set point
Working hours, motion sensor	Termostat/IR	21 °C
Working hours, no motion sensor	Termostat/IR	19 °C
Outside working hours	Termostat/timer	17-18 °C
Night cooling modus	Termostat/timer	10 °C

- Cooling: Two strategies were used for starting the night cooling. If the maximum temperatures during office hours (8-17) exceeded 25 C and/or if the average temperature during office hours (8-17) exceeded 24 C. Operation hours for night cooling could be e.g. between 21.00 and 6.30 stopping if the temperature drops below 17C. Control temperature should be measured (e.g. in overflow openings in 2. floor)

- Ventilation: Demand control in air inlet openings (VAV valves) based on motion control (IR) and temperature in cellular offices, team offices and meeting rooms and on CO2 concentration and temperature in landscape offices. Centralized measurement of CO2 and temperature in the overflow openings towards the atrium in each floor controls frequency of exhaust and supply fans.
- Lighting: The lighting system is controlled by presence detection and daylight sensors in all offices (cell office, team office, and landscape office).

Energy Performance

The performance of the building is reported to be:

- Heating demand: Predicted to be 26 kWh/m^{2}a.
- Cooling demand: No cooling demand is expected

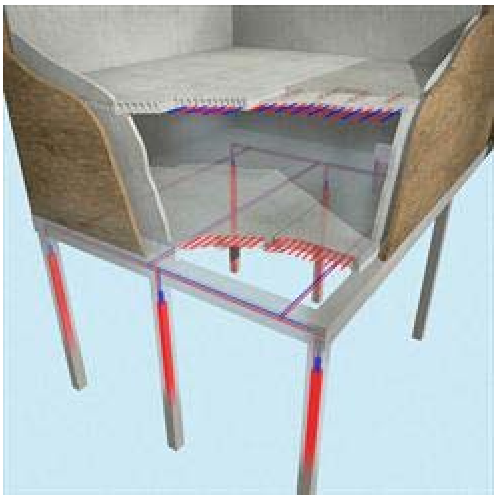
3.3.4 WelWonen House, the Netherlands

General data

Name of building	WelWonen House	
Year of construction	2005	
Type of building	New building, Ground floor and two upper floors.	
Use of building	Detached dwelling	
Heated/cooled building area	200 m^2	
Building owner	Private person	
Building leaser/tenants	n/a	
Location/address	Kampen, the Netherlands	
Geographic location	52°32'10" northern latitude 5°56'12" eastern longitude	Sea level +0.0 m
Situated (city or country side)	On the boundary of city and country side	

Architectural concept

Design Appproach



A consortium of Velta, Techneco and Betonson made it possible to combine the two proven concepts of Betonson's prefabricated thermo-active floor elements and energy piles into an energy-efficient heating and cooling system for dwellings. The system is complemented by a combination heat pump both providing space heating and hot water for domestic use.

The initiative of the concept was taken by Betonson in 2004 who wanted to combine two of its own proven concepts, prefabricated thermo-active floor elements and energy piles, into an energy-efficient heating and cooling system for dwellings. The primary goal was to reduce the costs for application of a heat pump by adding thermo-active building elements. The first house - from a private owner - that was realised with this energy concept was financially supported by SenterNovem, an agency of the Dutch Ministry of Economic Affairs.

A survey of the performance of different configurations of thermo-active floor elements and energy piles showed the feasibility of the concept in the proposed building design. Extensive monitoring of the realised concept showed great resemblance with calculation results and confirms the opportunity of the energy concept in dwellings.

Demand Reduction Strategies

The building is conventionally insulated with coefficients of heat transmission of: outside walls: U = 0.33 W/m²K; ceiling: U = 0.33 W/m²K and glazed areas: U = 1.7 W/m²K. Thermal bridges have been avoided by insulating thermal weak points and using suitable constructions.

Typical building constructions should guarantee a maximum infiltration (qv;10) of 0.625 dm³/s m² and the building is equipped with balanced ventilation with a high-efficiency heat recovery unit.

Responsive Building Elements

The following responsive building elements were used:

- Concrete core activated floor elements (prefabricated)

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Heating: Are realised through concrete core activated floor elements that provide both floor and ceiling heating to the different spaces and which are flown through with warm water (T_{flow} < 35°C). The upper floors are constructed from prefabricated concrete elements with embedded pipes, while the ground floor is realised onsite during the construction phase.
- Cooling: Are realised through the same system of activated floor elements and is used to provide free cooling from geothermal energy (energy piles). The concrete core activated floor elements are flown through with cold water (T_{flow} > 12°C) The heat pump is not in operation during the process of cooling.
- Ventilation: Balanced ventilation with heat recovery (recovery efficiency of 95%).

Renewable Energy Technologies

The following renewable energy technologies were used:

- Earth coupling with energy piles: Geothermal energy fuels the heating system and is derived from the soil by vertical heat exchangers integrated into construction piles, so called energy piles (21 energy piles - total active length of 210m). This concept drastically reduces investment costs while the placement of separate vertical heat exchangers is being avoided. The energy piles are also used to provide free cooling to the building during summer periods (in cooling mode the system bypasses the heat pump). During heating operation 5.4 kW is withdrawn from the energy piles, resulting in a specific capacity of 25.7 W/m. During cooling operation a peak capacity of 8 kW is extracted from the energy piles, resulting in a specific capacity of 38.1 W/m.

Efficient Energy Conversion

The following efficient energy conversion technologies were used:

- Heat pump: Electrical combi heat pump for space heating and domestic hot water extracting heat from energy piles. Nominal power 9,9 kW; COP 5.4 (T_{out} = 35 ˚C). Domestic hot water max supply of 200 l at max 60 ˚C; COP 2.5 (T_{out} = 55 ˚C)
- Ventilation: High efficiency fans and high efficient heat recovery (recovery efficiency of 95%).

Energy Performance

The performance of the building is reported to be:

- Heating demand: Predicted to be 38 kWh/m^{2}a. The average COP of the combi heat pump for space heating is calculated to be 3.9 from the start of the monitoring. For unknown reasons this average COP increases to approximately 4.6 after a certain period of monitoring. The average COP of the combi heat pump for domestic hot water supply is 2.2. The used calculation method of the COP includes storage losses (time difference between operation and actual tapping of hot water)
- Cooling demand: Free cooling The delivered cooling supply varies with the building's cooling demand. This causes the COP of the combi heat pump for space cooling to be at maximum during hot days, while the average COP is much lower. Monitoring showed a cooling demand of approximately 1200 hours in the summer of 2006, with an overall cooling supply of 1600 kWh. The electricity demand for space cooling (although the heat pump provides direct cooling without the need for a compressor, free cooling does require some energy for operating the pump) is about 97 kWh. Resulting in a COP for space cooling of 15.5.
- Primary energy demand: Predicted to be 101 kWh/m^{2}a (35% less than standard)
- Indoor environmental quality: Temperature control with aid of core activation/thermal mass is quite slow. This becomes especially important during the period between the heating and cooling season, where day-time temperatures are relatively high and night-time temperatures can be quite low. To decide whether the system is capable of establishing comfort simultaneously throughout the building, air temperature of all habitable rooms were monitored for a one-month period (September 2006).

  The temperature in all rooms stays more or less in the same range. The average temperature of the living room is 22.0 ˚C +/- 0.9 ˚C. In general the temperature of the living room swings the most, with an occasional peak value during late afternoon and a faster temperature-drop during night-time. Both effects can be explained from the large window areas.

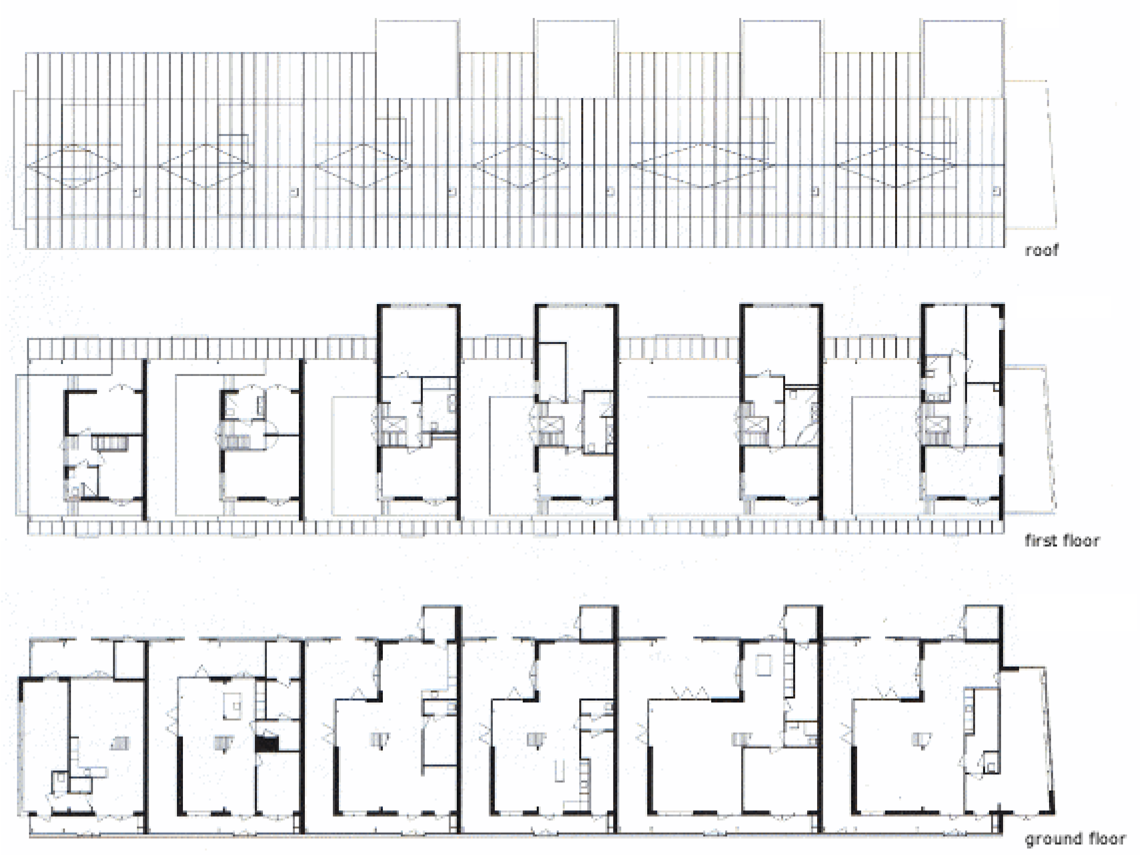
  Furthermore, the monitoring showed that the indoor and outdoor air temperature during a two-month relatively hot period (September/October 2006) even during hot days (day-time temperature above 28 ˚C and night-time temperature above 20 ˚C) did not exceed 24 ˚C.

3.3.5 Kaswoningen, the Netherlands

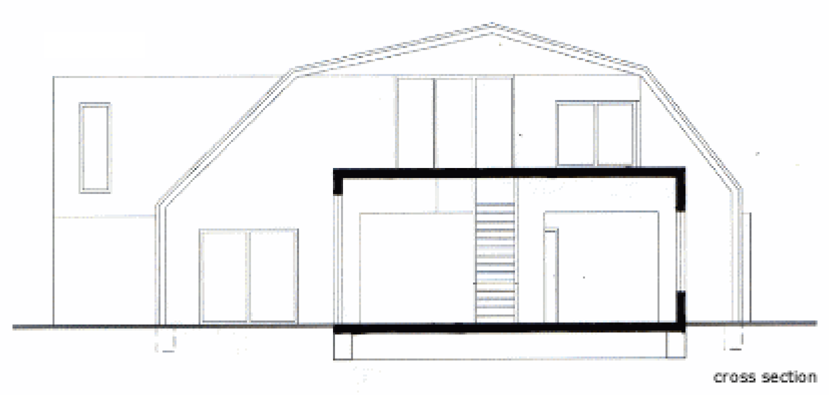
General data

Name of building	Kaswoningen or ‘solar space dwellings’ *	
Year of construction	2002	
Type of building	Newly built construction Core dwelling consist of ground and one upper floor. ‘Outdoor’ areas are located on both ground level and first level.	
Use of building	Six detached dwellings, some with a studio, sharing one spanning glass structure.	
Heated/cooled building area	872 m^2 (six core dwellings) ranging from 185 m^2 to 305 m^2 (including ‘outdoor areas’) Unheated ´outdoor’ areas : 487 m^2 (for six dwellings)	
Building owner	Six private persons	
Building leaser/tenants	n/a	
Location/address	Culemborg, the Netherlands	
Geographic location	51°56'48" northern latitude 5°13'59" eastern longitude	Sea level +2.7 m
Situated (city or country side)	Project is situated in EVA lanxmeer, an ecological urban development site. The location of the dwellings is very spacious but new construction is planned in the near future.	

Architectural concept



Floor plans [drawings from KWSA]



Cross section [drawing from KWSA]

Design Approach

The initiative of the development of the six dwellings was taken by two architects Arjan Karssenberg and Peter Weinberg, collaborating in the architectural firm KWSA. From their conceptual designs six private clients joined the project. The final layout for each dwelling was chosen in close cooperation with all clients.

The initial idea was to create a dwelling with sheltered outdoor areas. Areas that would be in close contact with its environment. Conventional solar spaces were not an option. In the architects' vision their construction would block too much of the outer environment (e.g. air, noise and light). A slender construction with a maximum of glass surface, just like as is used in the cultivation under glass industry, was their solution.

The presence of the solar space allowed the use of many untreated (natural) construction materials for the design of the core dwelling, while they were not exposed to dynamic climate conditions (e.g. wind, water). Therefore, construction detailing was also less stringent

The architects were managing the whole project including tasks that are commonly not performed by the architect, such as the acquisition of the building lot, selection of the contractor and supervision on both the construction phase and cost control. During the whole process of design and construction there was close consultation between architects and future occupants.

Demand Reduction Strategies

The energy concept consists of a highly insulated and thermal massive core dwelling which houses the living areas with the most demanding comfort standards (living room, bedrooms, bathroom, etc.). The back of the core dwelling is facing southwest and has tall windows to ensure high collection levels of solar gains for space heating and natural illumination. The core dwelling is placed within a glass structure that acts as thermal buffer and air lock.

Southwest orientated tall windows harvest maximum amounts of daylight and solar radiation.

The building coefficients of heat transmission are: outside walls: U = 0.23 W/m²K; ceiling: U = 0.21 W/m²K; foundation: U = 0.26 W/m²K and glazed areas: U = 1.47 W/m²K.

Responsive Building Elements

The following responsive building elements were used:

- Solar space: A glass structure that acts as thermal buffer and air lock and provide initial space heating.
- Night Ventilation: Night-time ventilation and a high thermal mass keep the core dwelling cool in summer

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Heating: Are realised through a floor heating system.

  Cooling: Are realised through natural air flows. Night-time ventilation and a high thermal mass keep the core dwelling cool.

- Ventilation: The solar space can be ventilated through many windows. They open automatically based on climatic conditions. Their function can be overruled by the occupants, if desired. The core dwellings are ventilated by means of opening its windows and doors. An additional balanced ventilation unit ensures a healthy indoor air quality, when natural ventilation is insufficient. Furthermore, the system is equipped with heat recovery and bypass, and is fully operable by the occupants

Renewable Energy Technologies

The following renewable energy technologies were used:

- Passive solar heating: Passive solar gains, solar buffering from the solar space provide passive heating to the core dwelling
- Photo Voltaic system: Photovoltaic cells contribute to the delivery of electricity. While their dimensions differ from the standards used in the cultivation under glass industry, they are placed hanging just underneath the roof of the glass structure Total of 20 panels ranging from 560-760 Wp per module, estimated return of 64 kWh/year per cell. Each cell has an estimated return of 80 kWh under standard test conditions. While the cells are placed within the glass structure, its efficiency drops proportional to the solar admittance of the glass used in the covering. The solar admittance factor of the glass dome is 0.8.
- Solar thermal system: A solar collector (with gas-fired backup system) provides additional heating, both for domestic hot water and space heating

Efficient Energy Conversion

The following efficient energy conversion technologies were used:

- Natural Gas Boiler: High-efficiency system Gas-fired backup system for heating
- Ventilation: Balanced ventilation with heat recovery and bypass. Heat recovery up to 95%

Energy Performance

The performance of the building is reported to be:

- Heating demand: Predicted to be 18 kWh/m^{2}a.
- Cooling demand: Free cooling with natural air flows during night ventilations.
- Primary energy demand: Energy performance estimation of the core dwellings showed approximately 50% less primary energy demand than the, at the time valid, standard.

Lessons learned

The main lessons learned were:

- Correct onsite execution of the proposed building design (e.g. construction details, service installations and their distribution system) is fundamental to achieve estimated levels of comfort and energy performance. This calls for post-manufacture inspection. With respect to technical installations such inspections on the proper functioning should be performed regularly during the period of occupancy.
- It is critical to inform the occupants about their share in the proposed climatic concept. They need to understand when their action is required and what the implications are if they don't intervene.
- Monitoring showed great differences between pre-design energy performance calculations and measured energy demand. Although these differences can be explained from ventilation behaviour, it does also raise the question if standards on energy performance calculations are a reliable method. Especially in this case of unconventional building design. For example, the dimensions of the 'outdoor' areas are not taken into account in energy performance calculations, however, their presence enlarges the living space significantly during much time of the year without the need for energy

The performance improvement due to integration of RBE included:

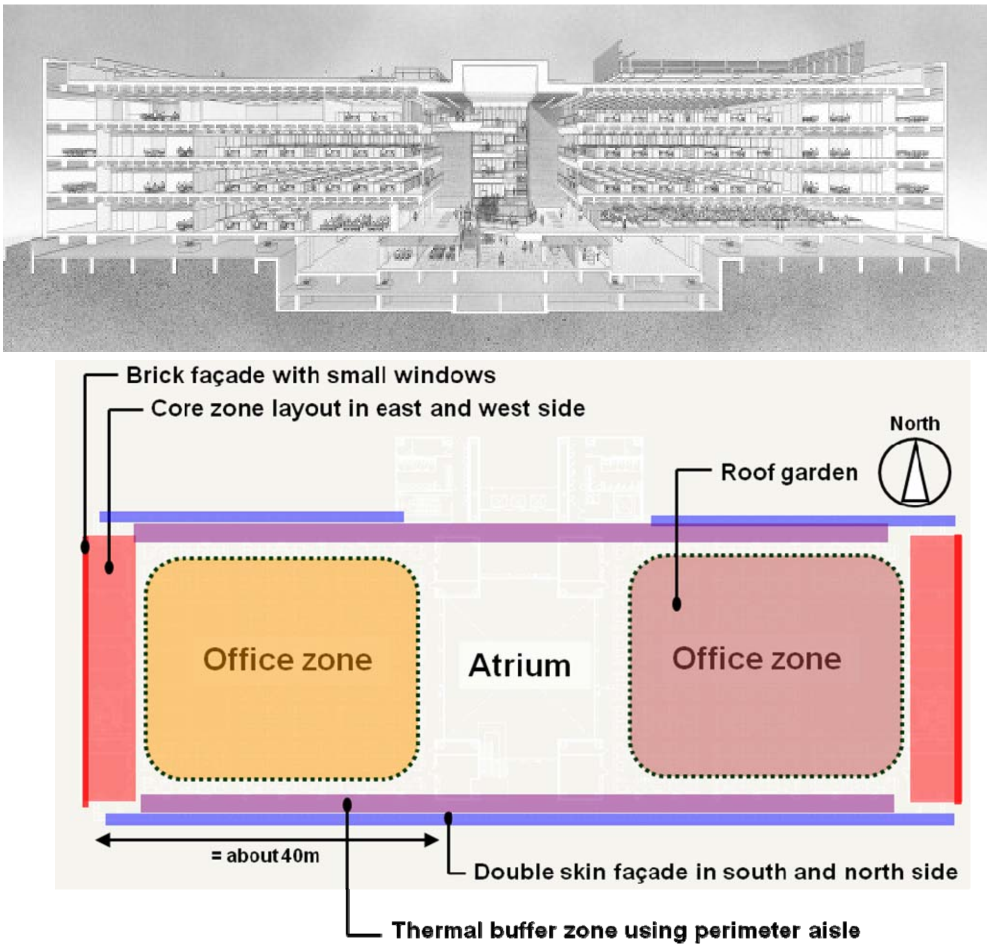
- Improved comfort by adding multiple 'outdoor' areas that can be used off-season. Reduction of temperature swings in the core dwelling by using thermal mass.
- Thermal buffering of the solar space reduces transmission losses.
- Performance of the integrated building concept
- The creation of 'outdoor' areas that can be occupied during certain times of the year, without the need for additional energy.
- Reduction of transmission losses of the core dwelling by applying the solar space as a thermal buffer.

3.3.6 Mabuchi Motor Industry Headquarters, Japan

General data

Name of building	Mabuchi Motor Headquarters
Year of construction	2004
Building type	4 story office building and one story basement, new construction
Building use	Office building
Building area	Total= 19,169 m^2
Building owner/	Mabuchi Motor Corporation
Location/address	Chiba, Japan
Geographic location	northern latitude eastern longitude — Sea level m
Context	Suburban area

Architectural concept



Architectural section and plan view of the office building.

Design Approach

The design of this facility tries to satisfy the client's demands for a comfortable and efficient work space with long life span, and for high design reliability and safety that also cares about the environment. The typical floor plan of the project is a space without columns with flexible spans of 33.6m (one wing has an area of 1500m2). Four floors are piled up towards the East-West wing and the central atrium is arranged in order to have an effective vertical floor communication, natural lighting and natural ventilation. The energy consumption of the air conditioning system is dominating the whole building. So it's very important to reduce the air conditioning load in the building design through passive methods as well as by making the active mechanical systems more efficient.

Demand Reduction Strategies

Optimum design of building layout with small windows and core zone layout in east and west side of the building to reduce air conditioning load. Thermal buffer zone at north and south facade behind double skin facade.

Naturally ventilated atrium to reduce air conditioning load.

Responsive Building Elements

The following responsive building elements were used:

- Double skin facade: supply functions which are necessary for an outer wall in Japanese climate, like heat insulation in winter, exhaust of heated air in summer and natural ventilation in spring and autumn. These functions are realized by the automatic controlling ventilation openings and dampers (dampers are installed at top, bottom and each floor).
- Thermal storage in the floor slab activated by air conditioning system and night ventilation. The floor slab is cooled during night time, which reduces the peak load during daytime and together with an ice storage shifts the peak electricity demand from daytime to nighttime. In shoulder seasons the air conditioning load can be reduced using cool outdoor air to cool the floor slab.
- Roof garden: to reduce solar load on roof area.

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Task and ambient air conditioning system with underfloor air supply to efficiently cool task zones in the large scale and high ceiling office at relatively high supply air temperatures (T_{supply} = 19-20°C). Air volume and direction is adjustable by the occupant.

Renewable Energy Technologies

The following renewable energy technologies were used:

- Natural ventilation of atrium
- Natural night cooling of floor slab in shoulder seasons

Efficient Energy Conversion

The following efficient energy conversion technologies were used:

- Ice storage system with gas fired absorption chiller and hot water unit

Energy Performance

The performance of the building is reported to be:

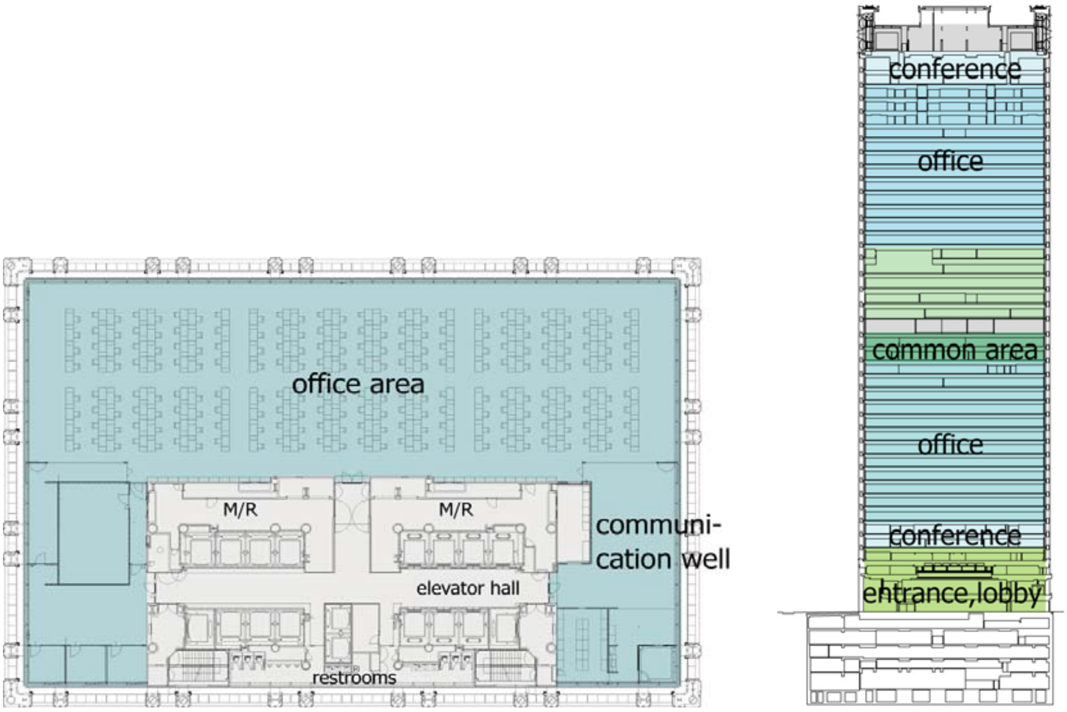
- Primary energy demand: Predicted to be 1657 MJ/m^{2}a (16% less than standard)

3.3.7 Kanden Electric Power Building., Japan

General data

Name of building	Kansai Electric Power Building	
Year of construction	2005	
Building type	41 story office building, 5 basement floors, new construction	
Building use	Office building	
Building area	Gross area 106,000 m^2, total net conditioned area = 60,000 m^2	
Building owner/	The Kanden Industries, Inc.	
Location/address	Osaka, Japan	
Geographic location	northern latitude eastern longitude	Sea level m
Context	City Center	

Architectural concept



Section and plan view of the office building (left: typical floor, right: section)

Design Approach

It is planned and designed with a concept, 'A model building of environmental symbiosis', to suggest a vision of new office buildings in the future. The building stands on the sandbank of the river crossing the city of Osaka from East to West. It is planned to utilize geographical advantage in the maximum. Specific plans are as follows; 1) Adoption of the 'Eaves' utilizing columns and beams to block a direct solar radiation, 2) Adoption of natural ventilation system to lead a river wind inside the building, 3) Adoption of district heating and cooling system utilizing the river water. In addition, new air conditioning and lighting system, which enable personal control to meet individual demands, are adopted to realize coexistence of energy saving and personal comfort comparing to 'uniform light and thermal environment' adopted in a conventional office.

Demand Reduction Strategies

"Eco-Frame", columns and beams jutted out by 1.8m outside from the window surface to block the direct solar radiation during 10AM to 2PM, the peak period of the cooling load in the summer time and low-e glass, is adopted to reduce inflow of heat from exterior. The cooling load in perimeter zone is greatly reduced (2/3 of a perimeter annual load to standard used in Japan), so that an air conditioning system for perimeter zone such as a fan-coil unit becomes unnecessarily. A "bottom up" solar shading assist in preventing direct solar radiation but allowing daylight into the office at high level.

Responsive Building Elements

The following responsive building elements were used:

- Thermal storage in the floor slab activated by air conditioning system and night ventilation. The floor slab is cooled during night time, which reduces the peak load during daytime and together with an ice storage shifts the peak electricity demand from daytime to nighttime.

Low Exergy Building Services Systems

The following low exergy building services systems were used:

- Task and ambient air conditioning system with underfloor air supply to efficiently cool task zones in the large scale and high ceiling office at relatively high supply air temperatures (T_{supply} = 18°C). Air volume and direction is adjustable by the occupant.

Renewable Energy Technologies

The following renewable energy technologies were used:

- Adoption of natural ventilation system to lead a river wind inside the building (reduces cooling load by 24%)
- Water-circulated river water heat exchanger are used as heat source for a heat pump and for “direct cooling” in the summer period. River water has a smaller temperature variation and improves heat pump efficiency

Efficient Energy Conversion

The following efficient energy conversion technologies were used:

- A large-scale ice thermal storage tank. Foundation pits of the building are used as the thermal storage tank of approx. 800m^3. Electricity at night is used to make ice used for a daytime air conditioning, so that electricity use at daytime is restrained. This leads to electricity load levelling to raise the generating efficiency at the power station and emission of CO_2 being restrained.
- Heat pump: Powered by electricity and extracting heat from river water

Control Strategy

The following control strategies were used:

- Personal control of air conditioning and lighting system to meet individual demands,

Energy Performance

The performance of the building is reported to be:

- Primary energy demand: Predicted to be 1657 MJ/m^2a (16% less than standard)

3.4 Controls for Integrated Building Concepts

3.4.1 Introduction: The need for controls

To maintain the optimum balance between the energy efficiency and the internal indoor conditions RBEs need to be controlled. However, controls need to be designed to operate with respect to a number of different requirements. The outdoor conditions as well as the availability of renewable resources are variable, and so is the demand for the indoor climate, depending on factors like activities, preferences and time of day. If well designed, controls can provide the right conditions for the inhabitants and the activities at the given moment, while saving energy by only providing it when and where necessary. However, in practice many controls turn out to be poorly functioning, causing discomfort to the user and nearly always leading to inefficient operation of the systems [1]. Therefore, some important aspects of control design are included.

3.4.2 Adaption

To be able to provide people with the essential control over their environment, while regarding energy efficiency, it is important to understand some basics of human behaviour to regulate thermal comfort, which is called *adaption*. According to Brager and De Dear [2] there are three categories of adaption;

1. Behavioural Adjustment:

   All modifications made to modify the thermal balance between body and environment, divided into three subcategories:

   a) Adjustment of personal variables to the environment, such as adjusting clothing, activity, posture, or moving to a different location.
   b) Adjustments to the environment, e.g. windows, fans, blinds and heaters.
   c) Cultural adjustments, including scheduling activities, siestas, dress codes

2. Physiological Adjustment:

   All changes in the physiological responses to thermal environmental factors which lead to a gradual diminution in the strain induced by these factors.

3. Psychological:

   An altered perception of and reaction to sensory information. This form of adaptation influences building occupants' "comfort set points" which vary in time and space. Relaxation of indoor climatic expectations can be associated with the concept of habituation in psychophysics; repeated or chronic exposure to an environmental stressor leads to a reduction of the induced sensation's intensity.

It is important to take note of the other types of adaptive behaviour of people for these will strongly influence the occupant's perception of comfort, and thus the range for the parameters to be controlled.

3.4.3 Usability

To design usable controls for operating an energy efficient and comfortable building, there are some essential design principles that need to be addressed. Leaman and Bordass [1] state the following;

1. What is the control for?

   There are two main reasons to include controls in a building:
   - To allow users to select the conditions they need and to avoid conditions they don't need.
   - To save energy and other resources.

2. When is the control used?

   The controls mostly are used on the following occasions:
   - When entering or leaving.
   - If the conditions don't suit them.

3. Who is the control for?

   The main groups of users are the following:
   - Occupants
   - Visitors
   - Maintenance staff
   - Building managers

4. Where should the controls be located?

   User controls should be placed at one or more of the following points:
   - The entrance to the space.
   - Near the item being controlled.
   - At the point of user(s) need.

5. Is the design intent clear to the end users?

   For the users to be able to use the control properly, the function of the control must be clear as well as the way to use it. The control should provide the following information:
   - The parameters controlled (temperature, ventilation)
   - The action to be performed by the user (turn, push)
   - The *direction* of the parameter (up, down)

6. Is the system status clear to the users?

   To enhance the sense of control of the occupant and its understanding of its environment it is crucial to provide the user with feedback to inform the user of the effects of the control action taken.
   - Give instant, tangible feedback (such as a click) to indicate to the user that the control has operated.
   - If possible, let the user see, feel or hear the controlled device operating or changing its status.
   - Give rapid feedback to show that the intended effect has occurred (readout, indicator light).

7. Are controls well integrated and energy efficient?
   - Automatic occupancy sensors combined with buttons.
   - Interval timer with off-button and necessary other override facilities,
   - Sometimes the control may need to give advice

8. How long should a user override last?

3.4.4 Control parameters

The control parameters are the basis for the strategy definition. A control parameter is any kind of information which could have an impact on the ventilation strategy. The information can be obtained directly by means of dedicated sensors or derived from a set of conditions. The occupant behaviour must be included in the scheme. The control parameters include [3]:

- Outdoor climate (temperature, humidity, pollutant level)
  - Temperature
  - Wind Speed
  - Humidity
  - Pollutant level
  - Solar Radiation
  - Precipitation

- Building or component characteristic
  - Provision for passive solar gains (RBE)
  - Opening / Closing windows
  - Light / Solar Transmittance (Shading / Shutters)
  - Thermal Insulation
  - Air tightness (ventilation)

- Ventilation system: airflows, pressure difference

- Indoor Climate:

    - Temperature
    - Ventilation
    - Humidity
    - Indoor Air Quality
    - Lighting
    - Hot Water

- Occupancy in habitable rooms (presence, or indirectly by CO2 level, humidity level, …)

- Odours in service rooms (kitchen, toilets),

- Humidity in service rooms (kitchen, bathroom)

The use of control variables depend on the type of control strategy that will be implemented. It could also be that the user is the one that processes the information to take certain action without any form of artificial intelligence.

The control modes can be the following:

- On/Off
- Discrete
- Modulating

3.4.5 Responsive Building Elements

RBEs are elements that respond to outdoor and indoor environment changes and occupants requirements in a proper way so as to keep optimal and adaptive comfort conditions, simultaneously contributing to minimize the energy consumption for the control of the indoor environment. Figure 1 illustrates the responsiveness and level of control providing examples.

Some RBEs can be controlled by influencing the direction and speed of the energy medium like water or air, or influencing other characteristics like insulation value (Dynamic Insulation) or transparency. Some techniques don't enable control, like thermal mass or PCMs. However, they function as decreasing fluctuations in temperature.

To the user, an RBE might work as a black box. Energy in some form is entering the system from outside, evoking a process that results to influence the climate indoors. In case of an operable window, the effects of opening and closing might be clear to the user, as well as conventional shading. However, in the case of Advanced Integrated Facades, this might not be clear to the user at all. To be able to provide the user with the necessary control, there should be an intelligent interface, that is clear to the user, and that controls the building element's performance to influence the indoor environment to the demand of the user, paying specific attention to readability and feedback to the user.

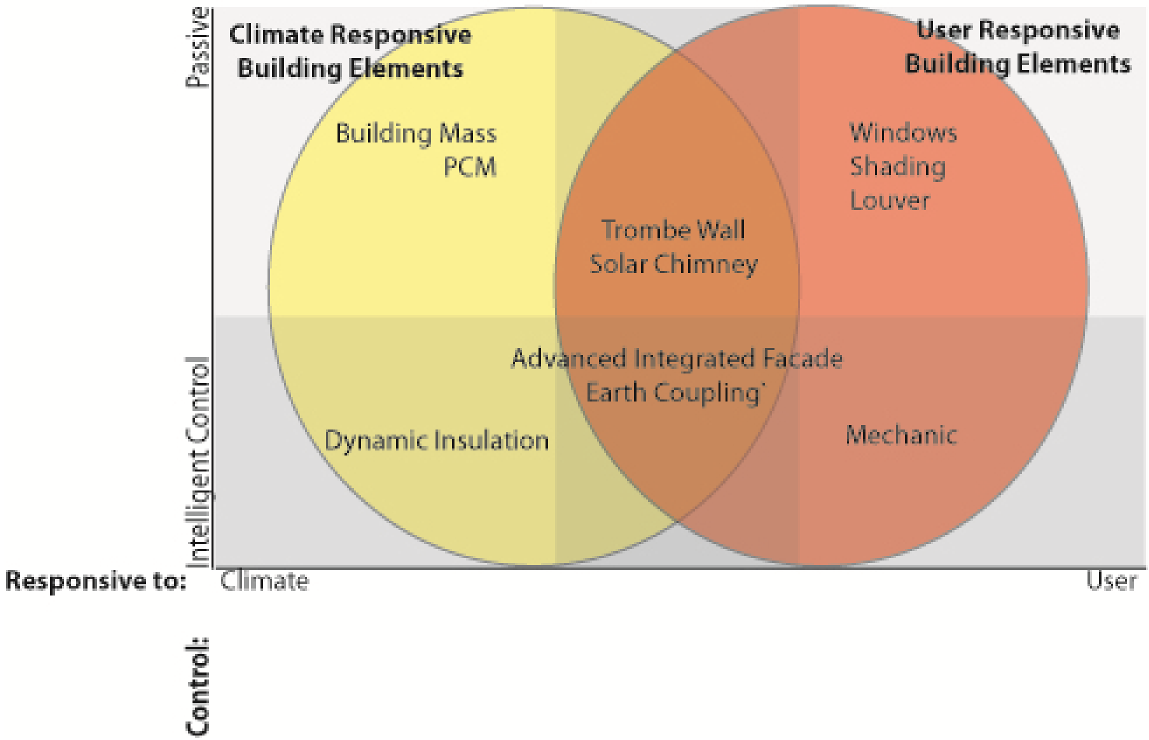


Figure 3.3: Responsiveness of climate systems

As can be seen in figure 3.3, certain systems can be both user responsive as climate responsive. Providing the user with control possibilities is very important, for it is proven by various studies that people are tended to accept a wider range of conditions as comfortable if they feel in control of their own environment.

The most advanced type of control is a Building Management System (BMS): a BMS is a system where components can communicate with each other and implies some form of central supervisor that permits monitoring and control of the building from one single point. This is the most advanced type of control and it can operate without any interaction of the user.

3.4.5 References

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4. Responsive Building Design, Performance Prediction and Evaluation

In order to facilitate the integrated design approach, different types of design methods and tools are used which makes it possible, in a strategic way, to select the most suitable technical solutions for the specific building and context.

This includes methods and tools, which can be used when decision makers (such as architects, project leaders, engineering consultants and so on) choose RBE's and other techniques into the building to be built and determine the specification of those techniques, so that the design objectives can be accomplished most effectively by applying the techniques.

The methods and tools enable both qualitative and quantitative evaluation of those techniques and the results can be fed back to the decision on the choice and the specification. There are different kinds of methods and tools applicable in different phases of the design process and for different kinds of RBE's and other techniques.

This section describes design methods and simulation tools that can be used for the selection of RBC and the evaluation of RBE's for inclusion in the design. It attempts to classify methods and tools according to Annex 44 RBC design phases and present some examples of developed methods and tools.

4.1 Classification

The purpose of this classification is to define/specify types of methods and/or tools suitable for the Annex 44 RBC design phases as defined in section 2.3, so that the potential user has an understanding of what is available and when to use it during the design phase.

PHASE 1

Building location and what to be built: This phase require decision instruments in the form of **design process methods**. In many countries green building rating systems have been developed that go beyond the requirements of building regulations and codes which will give strong steer on developing the brief. They result to overall indicative quantitative targets for the energy/environmental performance usually express as a total number on a predefined scale.

PHASE 2

Design Concept: Once a decision is reached to develop a building brief to achieve a certain green/energy rating and performance requirements, the design concept phase starts. During this phase **technology prioritisation tools** are needed to:

- Facilitate integrated design approach early in the design phase
- Facilitate communication between building services engineers and architects

- Help communication between clients and the design team

Recent design prioritisation tools go beyond energy simulation software and include general sustainable design considerations such as:

- Specific design strategies
- Materials selection
- Technologies selection including RBEs
- Evaluation of total building environmental performance (including energy)

Such tools ideally would be able to perform simulations of some simple generic integrated building concepts in the climatic conditions of interest to give some indication of expected performance of the different concepts.

Design prioritisation tools are very useful at the early design phase of a building to facilitate discussions between clients, designers and engineers before the building design progresses to a phase that systems and technologies cannot easily be changed.

Such discussion will lead to decisions on which RBEs would be considered for the building. These decisions would need to be further examined for their suitability during the preliminary design phase and verified during the performance evaluation phase using appropriate detailed simulation tools.

PHASE 3

Systems Design: This phase requires design simulation tools which can be used to evaluate the applicability of the selected RBE's. Such tools should have the capability of addressing all issues related to the energy and environmental performance of the building under consideration such as selected building materials and construction, internal and solar heat gains, environmental systems and controls plus the integration of RBE's in any particular design configuration. Therefore, such tools are climate and building type specific. In many cases **technology prioritisation tools** have the capability to be applied during the preliminary design phase and some technology specific preliminary design tools have been developed. In other cases, the capabilities of detailed simulation tools can be used to investigate the integration of RBE's by selecting a specific area of the considered building to carry out some parametric analysis.

Performance Evaluation: In this phase **energy/environmental simulation tools** are required to evaluate the performance of RBEs for the specific building; such tools would be integrated with detailed energy and environmental conditions simulation tools to predict the performance of RBE's for the specific building. If the required performance specified in phase 2 (concept design) is not achieved then the proposed RBE's need to be reconsidered by going back to the Phase 2.

PHASE 4

Component Design: Detailed energy/environmental simulation tools are required for this phase which would be similar to those required for phase 3 (performance evaluation). At this point of the design process, detailed sizing of RBE components is considered together with its integration with all building systems.

PHASE 5

Operation and Maintenance: This is a phase that increasingly attracts more attention in terms of energy performance. In Europe the introduction of the Energy Performance in Buildings Directive (EPBD) requires energy performance certificates to be displayed in public buildings. Energy performance certificates are also required for domestic buildings. Although in many cases this is based on predicted energy performance, operational performance is also required and for this integrated monitoring and evaluation tools would be an important addition to the existing design tools.

The discussion above indicates that individual methods and tools can be used for different purposes at different design phases. In general, design methods and tools can be divided into three categories:

1. Design **Process** Methods: These are design methodologies which describe the process of integrated design of buildings and/or systems within buildings.
2. Technology **Prioritisation** methods and tools: These are methodologies developed specifically to facilitate suitable choice of design methods and systems.
3. Energy/Environmental **Simulation** tools: These are tools which help consultants to carry out detailed analysis of the performance of a particular RBE and /or system.

The following section describes methods and tools considered within Annex 44, with explanations on how these can be used at different phases of the design process. It focuses on Technology Prioritisation methods and tools with the description of three examples developed by Annex 44 participants.

4.2 Methods and Tools Applicable in Phases 2 and 3

Three tools applicable to phases 2 and 3 of design process are described below. The first two are a combination of a design process method and technology prioritisation tools with specific application for residential buildings; the first was developed in Japan and the second in the Netherlands. The third is primarily a technology prioritisation tool for a specific technology (thermal mass activation) and applicable to office buildings in the UK.

4.2.1. LEHVE - Design guideline for residences in Japan

The Low Energy Housing with Validated Effectiveness (LEHVE), is a method to design a house, in which natural energy is fully utilized by taking climatic and surrounding conditions and residents' lifestyle into consideration. Envelope and building equipments are carefully designed or chosen in an integrated manner, comfort and convenience level are maintained or even improved, and CO_2 emission or primary energy consumption is reduced by 50% compared with standard houses in 2000.

As noted before, the design for the indoor environment and for the energy conservation is heavily related to the site condition and the residents' lifestyle. The shape and size of the building site, as well as the relationship with neighborhood buildings and the environmental quality of the district, is a determinant factor of possible or impossible design and choice. In addition, nature oriented mind/convenience oriented mind of the residents and tolerance to the stress due to thermal environment are also influential on the design. Taking the above recognition into consideration, the design flow of the LEHVE is depicted as Figure 4.1. (which is consistent with design phases described in section 2.3)

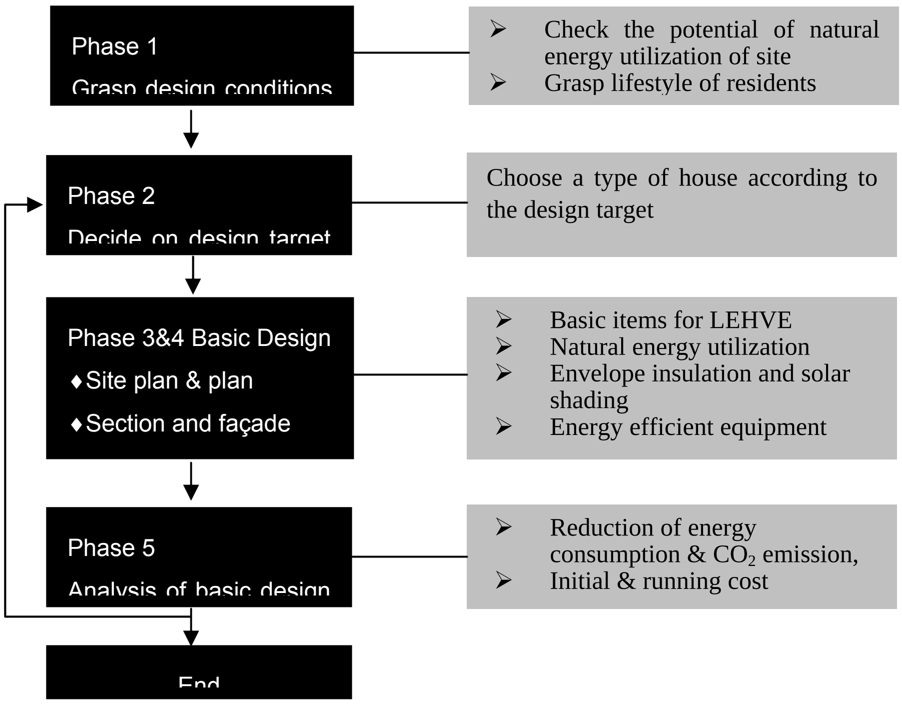

Figure 4.1 Design Flow for LEHVE

13 energy conserving technological elements

In the Design Guideline to LEHVE, thirteen technological elements, of which effectiveness has been validated by the experiment or reliable theoretical analyses, are adopted as shown in Table 4.1. The possible reduction of primary energy consumption by each technological element was quantified under the assumptions shown in Table 4.2. The reference energy consumption, which is predicted for conditions as usual specifications related to the thirteen technological elements, is shown in Table 4.3.

Table 4.1 Technological elements described in the Design Guideline to LEHVE

Grouping of Technological Elements	Thermal Environment Related	Airflow/Indoor Air Quality Related	Daylight/Artificial Light Related	Others
Natural Energy Utilization	1) Solar Heat Utilization 2) Solar Hot Water System	3) Natural Wind Utilization	4) Day Lighting 5) Solar Cell	-
Heat Control through Envelope	6) Envelope Insulation 7) Solar Shading	-	-	-
Energy-Efficient Equipment	8) Heating and Air-Conditioning Equipment 9) Domestic Hot Water System	10) Energy Efficient Ventilation for Indoor Air Quality	11) Energy Efficient Artificial Lighting	12) Electric Appliances 13) Water Treatment and Saving

Among the thirteen technological elements, three elements, namely, *envelope insulation*, *solar heat utilization*, *heating equipment,* are related to the heating energy consumption. Table 4.4 gives energy consumption ratios, by which reference energy consumption should be multiplied to predict reduced energy consumption (see Table 4.10 for a calculation example). As the reference condition (Level 0) of the envelope insulation, the insulation level of 1980 energy regulation is adopted, while as Level 1 and Level 3, the insulation level of 1992 and 1999 energy regulation are adopted, respectively. As Level 2, the insulation level of 1992 energy regulation for Region III is adopter, and the insulation level of 1999 plus requirement for higher performance openings is adopted as Level 4. When the envelope specification complies with Level 3, the heating energy is predicted to be 12.8 GJ x 0.55 = 7.04 GJ.

When the solar heat utilization is applied, the envelope insulation must be Level 3 or Level 4 as prerequisite condition. The solar heat utilization consists of three design methods, namely, *improved insulation performance of windows* (2.91 W/m^2K or less), *larger area of the windows facing south±30°*, of which ratio to the total floor area is equal to or larger than 0.2 and *larger heat capacity for interior finishing* than 120kJ/Km^2. The mud wall construction method of 70mm thick used for exterior and partition walls can comply with the condition for larger heat capacity. The energy consumption ratio for the solar heat utilization ranges from 1.0 to 0.6. In finding the ratio, there are three design conditions, namely, climatic condition according to the temperature and solar radiation (Passive Climatic Region, which has been prescribed in 1999 energy regulation), site condition for density and orientation of the building. For example, under the condition of Passive Climatic Region “ha” and Site Condition 3, the combination of Level 4 solar heat utilization and Level 3 insulation gives 0.6 as the energy consumption ratio, and the heating energy consumption is calculated to be 7.04 GJ x 0.6 = 4.22 GJ.

Table 4.2 Assumptions in the evaluation of possible reduction of energy consumption and CO_2 emission as well as possible difference of initial and running cost

Residents	Basic Building Characteristics
4 persons: 45 year-old husband, 42 year-old full-time housewife, 17 year-old high school girl, 15 year-old junior high school boy. Use of Time: determined by referring to the large scale survey carried out by NHK (Japan Broadcasting Corporation) Heating and Air-Conditioning Schedule: Intermittent schedule is determined by referring to questionnaire survey carried out by BRI. Continuous and overall schedule is also assumed independently. Possession of electric appliances: determined by referring to various surveys Use of electric appliances: determined by referring to detailed field measurement by BRI and AIJ	Building site: some residential area in a ward of Tokyo Area of the lot: 210m^2 Total floor area: 128m^2  Plan:

Table 4.3 Reference energy consumption (primary energy)for intermittent and continuous heating/air-conditioning

<table>
<tr><th rowspan="2">Energy Use</th><th colspan="4">Reference energy consumption (primary energy)</th></tr>
<tr><th colspan="2">Intermittent heating/air-conditioning case</th><th colspan="2">Continuous and overall heating/air-conditioning case</th></tr>
<tr><td>Heating</td><td>12.8 GJ</td><td>15.4 %</td><td>43.2 GJ</td><td>37.1 %</td></tr>
<tr><td>Air-Conditioning</td><td>2.4 GJ</td><td>2.9 %</td><td>5.3 GJ</td><td>4.6 %</td></tr>
<tr><td>Ventilation</td><td>4.7 GJ</td><td>5.6 %</td><td>4.7 GJ</td><td>4.0 %</td></tr>
<tr><td>Domestic Hot Water</td><td>24.5 GJ</td><td>29.4 %</td><td>24.5 GJ</td><td>21.0 %</td></tr>
<tr><td>Lighting</td><td>10.7 GJ</td><td>12.9 %</td><td>10.7 GJ</td><td>9.2 %</td></tr>
<tr><td>Electric Appliances</td><td>23.7 GJ</td><td>28.5 %</td><td>23.7 GJ</td><td>20.3 %</td></tr>
<tr><td>Cooking</td><td>4.4 GJ</td><td>5.3 %</td><td>4.4 GJ</td><td>3.8 %</td></tr>
<tr><td>Total</td><td>83.2 GJ</td><td>100.0 %</td><td>116.5 GJ</td><td>100.0 %</td></tr>
</table>

Energy calculation for different uses

(1) Heating (Table4.4)

Energy consumption for heating and air-conditioning is clearly different between intermittent and continuous schedules. The schedule for heating and air-conditioning is dependent on the lifestyle of the residents and on their consciousness of various aspects.

Table 4.4 Heating energy and related technological elements (for intermittent heating)

<table>
<tr><th rowspan="2">Energy use</th><th rowspan="2">Ref. Energy</th><th rowspan="2">Tech. Element</th><th rowspan="2" colspan="2">Design methods</th><th colspan="5">Energy consumption ratio(reference energy=1.0)</th></tr>
<tr><th>Level 0</th><th>Level 1</th><th>Level 2</th><th>Level 3</th><th>Level 4</th></tr>
<tr><td rowspan="5">Heating</td><td rowspan="5">12.8GJ</td><td rowspan="2">Envelope Insulation</td><td rowspan="2" colspan="2">Energy Conservation Law</td><td>1.0</td><td>0.8</td><td>0.65</td><td>0.55</td><td>0.45</td></tr>
<tr><td>1980 regulation</td><td>1992 regulation</td><td>In between 1992 and 1999 regulation</td><td>1999 regulation</td><td>1999 regulation plus highly insulated windows (K<2.91 W/m2K</td></tr>
<tr><td rowspan="3">Solar heat utilization</td><td colspan="2">Methods:
1.imprved window,
2.larger windows,
3.larger heat capacity</td><td>1.0</td><td>0.95</td><td>0.9</td><td>0.8</td><td>0.6</td></tr>
<tr><td rowspan="2">“I” or “Ro” region</td><td>Site 3 0-15°</td><td>-</td><td></td><td>1, 1+2, 1+3</td><td>1+2+3</td><td rowspan="2"></td></tr>
<tr><td>Site 3 15-30°</td><td>-</td><td></td><td>1, 1+2, 1+3, 1+2+3</td><td></td></tr>
</table>

				Site 2 0-30°	-	1, 1+2, 1+3, 1+2+3			
			"Ha" region	Site 3 0-15°	-		1	1+2, 1+3	1+2+3
				Site 3 15-30°	-		1	1+2, 1+3, 1+2+3	
				Site 2 0-15°	-	1+2, 1+3	1+2+3		
				Site 2 15-30°	-		1+2+3		
			"Ni" or "Ho" region	Site 3 0-30°	-		1	1+2, 1+3	1+2+3
				Site 2 0-15°°	-	1+3	1+2	1+2+3	
				Site 2 15-30°	-	1+2	1+2+3		
		Heating Equipment	Air-Conditioner	COP	1.0	0.8	0.7	0.6	
					<4.0	>=4.0	>=5.0	>=6.0	
			Hot Water Floor Heating + A.C.	Methods: 1.Insulation for pipe, 2. Higher COP of A.C.	No insulation for pipe	Insulated pipe as required	Insulated pipe as required	Insulated pipe as required	
					<4.0	>=4.0	>=5.0	>=6.0	

The heating energy is also related to the efficiency of the heating equipment. Among different kinds of the equipment, only heat pump air-conditioner with COP higher than 4.0 and hot-water floor heating system have been validated of their effectiveness to reduce heating energy. Instead of the heat pump air-conditioner with COP less than 4.0, when that with COP of 6.0 is used with the above mentioned envelope specification, the heating energy can be reduced to 4.22 GJ x 0.6 = 2.53 GJ.

(2) Air-Conditioning (Table 4.5)

Three elements, namely, *natural wind utilization, solar shading and air-conditioning equipment* are related to the cooling energy consumption. Table-5 gives energy consumption ratios, by which reference energy consumption should be multiplied to predict reduced energy consumption. By utilizing natural wind, the building can be cross ventilated and indoor accumulated heat due to solar heat gain and internal heat load can be dissipated, especially during night or medium seasons. The natural wind utilization consists of four design methods, namely, *multiple openings on facades with different wind pressure of each room (direct method), utilization of wind catcher such as wing wall (indirect method), utilization of buoyancy-driven ventilation, internal openings on partition walls, etc. (allowing smooth airflow* *path between divided rooms/space).* Another passive cooling technology is solar shading, which consists of *building orientation and lower solar heat gain coefficient of windows.* According to a certain simulation result, the cooling load for a house facing to South East or South West is 1.3 times larger than a house facing to South, for example. With choosing more appropriate orientation, solar shading devices such as an exterior blind should be used to reduce solar heat gain coefficient. For example, when the main façade of the building faces to south and the solar heat gain coefficient is 0.55 for openings facing to North±30° and is 0.45 for other openings, cooling energy can be 0.7 times, compared with the reference case. The solar heat gain coefficient is dependent on the existence of eave, glass specification and the utilization of solar shading devices other than the eave. In addition, the efficiency of the air-conditioner is the last determinant of the cooling energy consumption.

Table 4.5 Cooling energy and related technological elements (for intermittent cooling)

Energy use	Ref. Energy	Tech. Element	Design methods		Energy consumption ratio(reference energy=1.0)				
					Level 0	Level 1	Level 2	Level 3	Level 4
Cooling	2.4GJ	Natural wind utilization	Methods: 1.direct method, 2.indirect method, 3.roof window, 4.buoyancy driven ventilation, 5.internal openings		1.0	0.9	0.8	0.7	
					-	Site 3: 1+5, Site 2: 2+3+5 Site 2: 4+5	Site 3: 1+2+5 Site 2 2+3+4+5	Site 3: 1+2+3+4+5	
		Solar Shading	Orientation of main facade	South	1.0	0.85	0.7	0.55	
				South East or South West	1.3	0.8	0.75	0.65	
				East or West	1.1	0.8	0.75	0.65	
			Solar heat gain coefficient	North±30°	About 0.79	<=0.79	<=0.55	<=0.55	
				Other orientation	About 0.79	<=0.60	<=0.45	<=0.30	
		Cooling Equipment	A.C.	COP	1.0	0.8	0.7	0.6	
					<4.0	<5.0	>=5.0	>=6.0	

(3) Energy Efficient Ventilation (Table 4.6)

For the reference case, a balanced ventilation system with duct but without heat recovery is assumed, and its electric consumption and annual energy consumption (primary) are 55W and 4.7 GJ, respectively. The energy efficient ventilation consists of four design methods, namely, *reduction of pressure loss through duct and other components, utilization of DC motor, hybrid ventilation, simplification of the ventilation system.*

Table 4.6 Ventilation energy and related technological elements (for overall ventilation)

Energy use	Ref. Energy	Tech. Element	Design methods	Energy consumption ratio(reference energy=1.0)				
				Level 0	Level 1	Level 2	Level 3	Level 4
Ventilation	4.7GJ	Energy Efficient Ventilation for Indoor Air Quality	Methods: 1.reduction of pressure loss, 2. utilization of DC motor, 3.hybrid ventilation, 4. simplification of the ventilation system	1.0	0.7	0.6	0.4	
				Balanced ventilation system as usual	1 or 2	1+2	1+2+3+4	

(4) Domestic Hot Water (Table 4.7)

Energy consumption for domestic hot water is the largest among different energy uses in a mild climate region (Table 4.3). For the reference case, a gas instant water heater without hot-water tank, of which efficiency has been validated to be 0.785 by the experiment, is assumed. There are four design methods included in this technological element, namely, *solar hot water tank (not connected to any boiler, but with hot-water supply pipe to bathtub), solar heat collector connected to hot-water tank or boiler, energy efficient heat source and utilization of well insulated pipe and faucet with thermostat or single lever.* As energy efficient heat source, a latent heat recovery gas instant water heater and a CO_2 heat pump are validated of their effectiveness in the experiment with simulated human occupancy. In the experiment, hot water use pattern for 4-member family, which is called “Corrected M1 Mode” is developed and applied. It should be noted that the effectiveness has been validated only for the family size.

Table 4.7 Domestic hot water energy and related technological elements

Energy use	Ref. Energy	Tech. Element	Design methods	Energy consumption ratio(reference energy=1.0)				
				Level 0	Level 1	Level 2	Level 3	Level 4
Domestic hot water	24.5GJ	Solar Hot Water System, Domestic Hot Water System	Methods: 1. solar hot water tank, 2. solar heat collector, 3-1. latent heat recovery gas instant water heater, 3-2.CO_2 heat pump, 4. utilization of well insulated pipe and faucet with thermostat or single lever	1.0	0.9	0.8	0.7	0.5
				Conventional gas water heater	1 or 3-1or 4	1+3 or 3+4 or 3-2	2 or 1+3+4	2+3 or 2+3+4

(5) Lighting (Table 4.8)

Two technological elements, namely, *day lighting and energy efficient artificial lighting* are proved to be related to the lighting energy consumption. The day lighting performance is evaluated by the number of facades with window(s) for each room (living/dining room, family member's bedroom other than a master's bedroom, kitchen, bathroom, toilet, washroom and hall) and building site condition related to the density. The effectiveness of the day lighting especially in the living/dining room and private rooms of elderly family members or children is assumed to be remarkable. When all of these rooms have windows on at least two different facades and the house is located in Site Condition II, where any special consideration is needed for day lighting design, 2-3% lighting energy reduction is possible.

As for the energy efficient artificial lighting, there are three different methods, namely, *efficient lamp and apparatus, automatic control by using sensor(s) and multiple distributed lightings rather than centralized single light in each room.* The maximum reduction by using all of these methods is 0.5.

Table 4.8 Lighting energy and related technological elements

Energy use	Ref. Energy	Tech. Element	Design methods	Energy consumption ratio(reference energy=1.0)				
				Level 0	Level 1	Level 2	Level 3	Level 4
Lighting	10.7GJ	Day lighting	Number of facades with window: 1.two facades only in LD, 2.two facades in LD and private rooms occupied in daytime, 3. two facades in LD and private rooms occupied in daytime, and one façade in hall, etc.	1.0	0.97 - 0.98	0.95	0.9	
				Only one façade with window in LD and private rooms	Site 3: 1 Site 2: 2 Site 1: 3	Site 3: 2 Site 2; 3	Site 3: 3	
		energy efficient artificial lighting	Methods: 1. efficient lamp and apparatus, 2. automatic control by using sensor(s), 3. multiple distributed lightings rather than centralized single light in each room	1.0	0.7	0.6	0.5	
				Conventional lighting equipment	1	1+2	1+2+3	

(6) Other Use (Table 4.9)

According to Table 4.3, energy consumption for electric appliances (23.7GJ) equals to that for domestic hot water (24.5GJ), when heating and air-conditioning are intermittent. Energy efficiency of refrigerator, television set, heated toilet seat (most important electric appliances), electric hot water pot and clothes washing machine (important electric appliances) has been improved year by year. The refrigerator of 400L produced in 2003 consumes 200kWh/a, while that produced in 2000 consumes 450kWh/a. A television set with 28inch liquid crystal display produced after 2001 consumes 250kWh/a less electricity than that is with 28inchi cathode-ray tube display and was produced before 2000. When these refrigerator and television set are used, 20% reduction of energy consumption for electric appliances is accredited. In addition to using energy efficient types for all of

these "most important" or "important" electric appliances, when countermeasures to reduce standby mode electricity audio appliances for MD, CD, DVD and video tape, personal computer, telephone/fax, microwave oven, TV game, etc., 40% reduction of energy consumption for electric appliances is accredited.

As for cooking ovens, the comparative experiment for gas cooking oven and IH heater was carried out with 5 subjects each, and any significant difference of primary energy consumption has not yet been found. Generated electricity by a photovoltaic cell of 3kW or 4kW generation capacity can be deducted from the total primary energy consumption, depending upon the location. When the house is built in Tokyo, the deduction is 29.3 GJ for 3kW and 39.1 GJ for 4kW.

Table 4.9 energy for electric appliances/cooking, power production by PV and related technological elements

Energy use	Ref. Energy	Tech. Element	Design methods	Energy consumption ratio(reference energy=1.0)				
				Level 0	Level 1	Level 2	Level 3	Level 4
Electric appliances	23.7GJ	Electric Appliances	Year of production	1.0	0.8	0.6		
				Owned in around 2000	Product after 2003 (-500kwh)	Product after 2003 and reduced stand-by mode electricity (-1000kwh)		
Cooking	4.4GJ	-	-	1.0				
				Gas oven or IH cooking heater				
Power Production		Photovoltaic cell	Capacity of PV	±0GJ	29,3GJ	39.1GJ		
				Not applied	3kW PV	4kW PV		

Calculation summary

Once the specification is determined for the first twelve technological elements, by referring to Table 4.4~4.9 the total primary energy consumption can be calculated. An example is shown in Table 4.10, in which 47% energy reduction is predicted without photovoltaic cell.

Table 4.10 Example of total primary energy calculation

(Figures in [ ] are energy consumption ratios shown in Table 4.4~ 4.9)

Energy use	Calculation*	Prediction (GJ)	Reference energy consumption (GJ: primary energy)	Reduction ratio (%)
Heating	12.8 × ([0.55] × [0.9] × [0.6])	3.8GJ	12.8GJ	-70%
Cooling	2.4 × ([0.8] × [0.55] × [0.6])	0.6GJ	2.4GJ	-75%
Ventilation	4.7 × [0.6]	2.8GJ	4.7GJ	-40%
Domestic Hot Water	24.5 × [0.5]	12.3GJ	24.5GJ	-50%
Lighting	10.7 × ([0.95] × [0.6])	6.1GJ	10.7GJ	-43%
Electric Appliances	23.7× [0.6]	14.2GJ	23.7GJ	-40%
Cooking		4.4GJ	4.4GJ	±0%
Subtotal		44.2GJ	83.2GJ	-47%
Power Generation	3kW: -29.3GJ/4kW: -39.1GJ	-0GJ		
Total		44.2GJ	83.2GJ	-47%

Conditions: *envelope insulation*/Level 3, *solar heat utilization*/Level 2 (methods 1+2+3, facing south in site with 5-hour-sunlight on the winter solstice), *heating equipment*/Level 3, *natural wind utilization*/Level 2 (methods 2+3+4+5, in Site 2), *solar shading*/Level 3 (solar heat gain coefficient<=0.3 except for north±30°), *air-conditioning equipment*/Level 3, *energy efficient ventilation*/Level 2 (duct diameter>=75mm, consideration in layout of supply terminals), *domestic hot water*/Level 4 (solar heat collector+ well insulated pipe/bath tub and faucet with thermostat or single lever), *day lighting*/Level 2 (every room has windows on different facades, hall with a window, in Site 2), *lighting*/Level 2 (efficient lamp and apparatus, automatic control by using sensor(s)), electric appliances/Level 2

4.2.2. Toolkit for sustainable residential buildings in the Netherlands

Using the principles of Trias Energeticas method and the Kyoto Pyramid (see section 2.3.) a toolkit has been developed in the Netherlands to assist with all design phases of residences. As it is the case with the Japanese Design Method for Houses, the Dutch Toolkit is country and climate specific. It is available on line (in Dutch) for designers that would like more information (www.toolkitonline.nl).

The toolkit is in the form of a spreadsheet which has captured simulations of a large number of integral design concepts suitable for Dutch houses and has also set performance criteria in terms of internal environmental quality, energy performance and environmental impact performance.

The call for a toolkit came from the building sector where the conclusion was drawn that inventing the wheel for every new building project leads to unclear design targets and financial budgets, an uncontrolled development process, large failure costs exceeding of budgets etc. An important point of departure at the beginning of the development of this Toolkit was that energy is not the only and certainly not the most important selling point for new houses, but the integrated quality, formed by a lot of items, is important. So, first of all the location, the safety, the visual performance, the flexibility, the accessibility, etc. are the items people select their house on. Meanwhile there is a large interaction between all these items and a number of them influence the comfort and energy quality of the building. Therefore so called quality profiles were made, from which the quality aspects of a dwelling can be defined in the very early phase of the development. Under these quality aspects health, comfort and energy defined, among 4 quality aspects for the location and 12 quality aspects for the building. Per quality aspect 3 levels of ambition can be chosen. Based on the level of ambition it is possible to zoom in until the level of detailed requirements to apply.

Once the quality level is defined one can chose out of a list of applicable concepts that has been selected from a list of 300 already calculated integrated building concepts. The calculated items are among others energy performance targets, energy consumption, CO_2-emission, investment costs, exploitation costs etc.

As mentioned before, the concepts have been designed based on an integrated design strategy following the Trias Energetica principles. For 30 often applied concepts an extended work out and full description with targets, process issues, crucial aspects, technical and financial (costs and exploitation) aspects, quality control etc has been made. Together with the focus on energy, health and comfort also specific attention has been paid to the application of sustainable materials and industrial and flexible building.

The Toolkit in practice shows to fill in a need for information in the building sector in the early phase of the project development. It removes uncertainties and gives guidance for an integrated design. The large building development companies and contractors pick out their “own” concept and improve and standardize this in co-operation with co-makers.

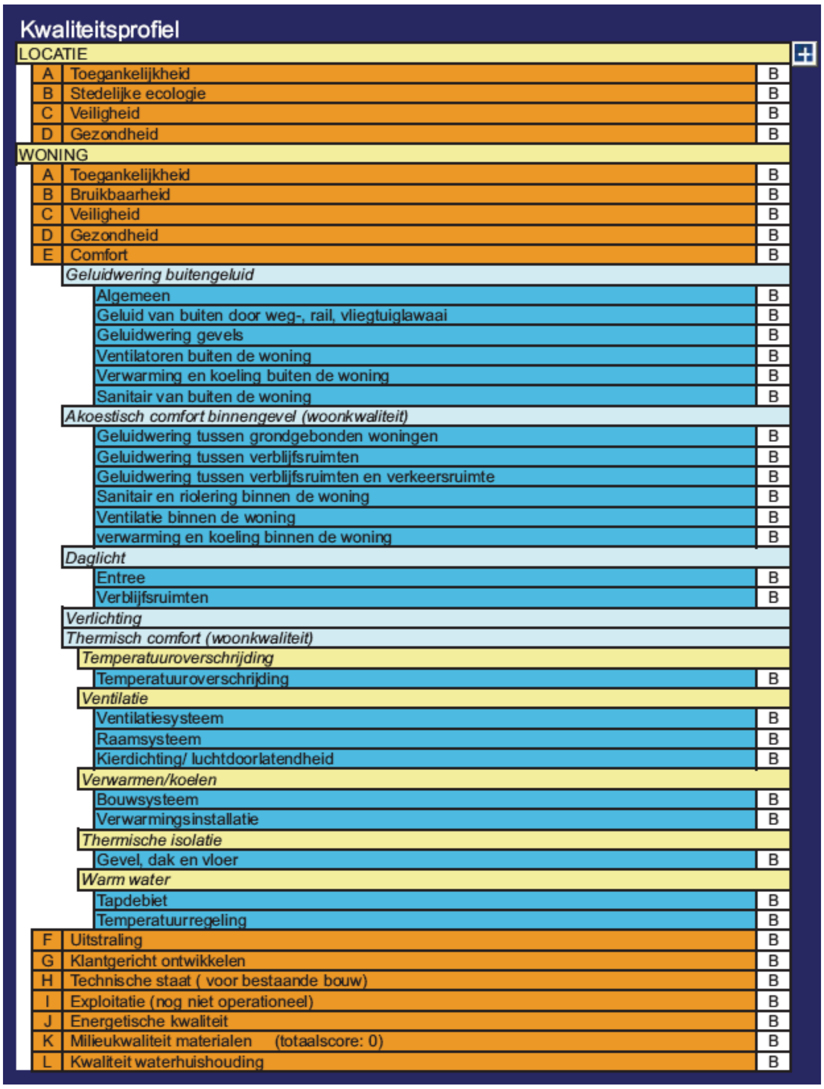

Figure 4.2. Quality profiles of the Toolkit

Finally, one of the most important questions in design process of the energy saving buildings is the cost-benefit relation of individual measures. As the interaction between the individual measures in an integrated design concept is big, this question is not easy to be answered. Increasing the insulation level of a building decreases the heating demand. How much, however depends i.e. on the thermal inertia of the building and the efficiency of the heating system. On the other hand an increase of the insulation level will affect the cooling load during summer. This means that for integrated building concepts it is quite complicated to determine effects for individual measures.

Based on the simulation results of the 300 integrated concepts for residential buildings an analysis has been made about the spread in cost versus energy performance of the various concepts. Reference point is the legal level of the building regulations (zero additional costs). The analysis results are given in figure 4.3.

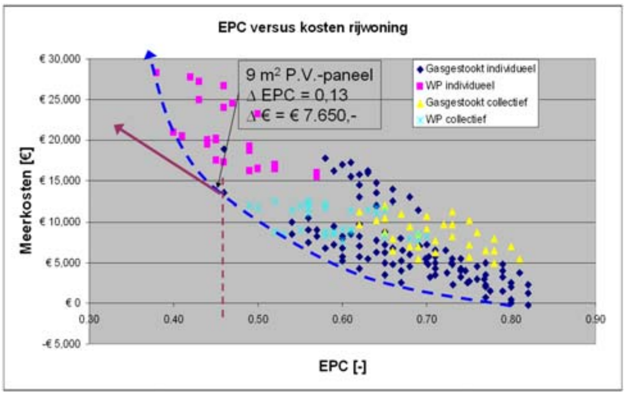

Figure 4.3 Additional cost versus EPC for integrated concepts

Based on this spread a line can be drawn that represents the most effective concepts. The gradient of the line is increasing as the energy performance requirements are increasing. From this it can be seen that the law of diminishing returns counts is applicable for piling up energy saving measures. For solitary measures that do not have an interaction with other measures (i.e. photovoltaic's) depending on the tangent line of it's cost-benefit relation it can be determined at which level this technology is beneficial to apply.

References

Hameetman Pieter; De Haas, Frans; Van der Aa, Ad (2006) *Toolkit duurzame woningbouw*. www.toolkitonline.nl

Van der Aa A and Heiselberg P (2008) A design process for integrated building concepts with responsive building elements AIVC conference 14-16 October, Kyoto, Japan Vol 2, pp 47-52

4.2.3 TMAir – Simplified Tool for thermal mass activation strategies in office buildings in the UK

TMAir is a simplified design tool (technology prioritisation tool) that can be used at phases 2and 3 of a typical office building to determine the benefits of integrating an active thermal mass strategy. The tool was developed by carrying out simulations using a dynamic thermal model which was calibrated by measurements in operational buildings with active thermal mass in the UK.

Four active thermal mass strategies are considered

(a) hollow core slabs

(b) earth-to-air heat exchanger

(c) floor void with mass and

(d) thermal labyrinth in addition to a standard office with no active thermal mass.

Key design parameters were identified for each system and parametric analysis was carried out to determine the resulting environmental conditions and energy consumption in the office. The tool has an easy-to-use interface which allows direct comparison of the different active thermal mass strategies together with the effects of changing key design parameters. Results are presented in terms of thermal comfort and energy consumption. It is available to download from http://annex44.civil.aau.dk

Method of Tool Development

Technology prioritisation tools can be divided into two main categories:

- Results are extracted from built-in databases derived from advanced modelling for a specified number of cases (in the form of parametric analysis) and weather data (usually country restricted).
- Results are calculated from built-in (usually energy and thermal) simplified or fast-to-run algorithms.

It was chosen to develop the tool using the ‘database’ approach. This was for two reasons (1) the results would be based on detailed and advanced modelling allowing the use of calibrated models, and therefore more accurate (2) misinterpretation of the results would be more difficult due to the options within the design tool being restricted.

Dynamic thermal models calibrated by measurements from operational buildings with active thermal mass strategies in the UK were used to carry out simulations for all of the combinations of the parameters above (900 simulations).

A database was created with the simulation results and a user interface was created within Microsoft Excel. A description of the available input and outputs for the user are presented below. The database allows the user to select a base option and four other options for comparison.

Method of Tool Development

To allow the effects of integrating an active thermal mass strategy into an office building, together with the effects of space design and use, a number of parameters have been explored. These parameters can be split into two categories; fixed parameters and user selected parameters. The fixed parameters are pre-selected for the design tool and have to be a fair representation of the projects that the tool will be used for.

The user selected parameters are chosen by the user to represent the way the building will be used, and to look at the effect of key design decisions on the performance of the building.

Fixed Parameters

Office Type: The simulation results were based on a single office cell 10m wide, 6m deep and 3m high The cell has one external wall and is located on a middle floor with the rooms above and below conditioned similarly to the test room (see figure 4.4).

Weather Data: The model has been simulated using CIBSE Design Summer Year (DSY) 2005 weather data for London.

User Selected Parameters

Active Thermal Mass Strategy

Active Thermal Mass Strategies can be used to enhance the performance of thermal mass by passing air or fluid across the surfaces with high thermal mass. Four Active Thermal Mass Strategies can be selected:

a) Active Hollow Core Slabs: Hollow core pre-cast concrete slabs are used as a path for supply air thus increasing the coupling between the thermal mass and the supply air attenuating variations in ambient air temperatures.

b) Floor Void with Thermal Mass: A void created between a raised floor and a structural concrete slab as a supply air plenum, again increasing the coupling with the thermal mass and supply air.

c) Earth to Air Heat Exchanger: An earth-to-air heat exchanger draws ventilation air through ducts buried underground.

d) Thermal Labyrinth: A thermal labyrinth decouples the thermal mass from the occupied space by creating a concrete undercroft, increasing the surface area of thermal mass, beneath the building. The benefits of decoupling the mass are that it can be cooled lower than if it was in the occupied space and the stored ‘coolth’ can be used to condition the occupied period for up to 3 or 4 days in hot periods.

Service Strategy

When a space has high internal heat gains an active thermal mass strategy will not have enough storage capacity to overcome these loads and provide a comfortable environment. In these cases cooling may be required. To analyse the effect an active thermal mass strategy has when coupled with a cooling system two different service strategies can be selected.

a) Mechanical Ventilation – the supply air is heated to meet the heating load of the test room in the winter period; in the summer period ambient air is supplied directly to the test room.

b) Comfort Cooling - the supply air is heated to meet the heating load of the test room in the winter period; additionally the supply air is cooled to meet the cooling load of the test room in the summer.

Air Flow Rate

The internal heat gains, and therefore the occupancy, together with the solar gains to the test room are changeable within the tool. The amount of air required to achieve the minimum fresh air rate or the amount of air required to meet the cooling demand of the space therefore varies. Air change rates of 1, 2, 6, 8 and 10 $achr^{-1}$ have been included to allow the user to select an air flow rate suitable for the internal and solar gains that have been selected.

Table 4.11: Internal Heat Gains

	Density of Occupation ($per \cdot m^{-2}$)	Sensible Heat Gain ($W \cdot m^{-2}$)	Latent Heat Gain ($W \cdot m^{-2}$)
High	4	57	15
Medium	8	42	7.5
Low	20	26	3

Internal Heat Gains

The internal heat gains were defined using data from CIBSE Guide A. Three levels of internal heat gain can be selected (see table 4.11).

Night Cooling

Night cooling is a low energy strategy for maximising the benefit of internal thermal mass. Ventilation is used to cool the internal surfaces of a building at night. During the following day a portion of the buildings heat gains are then absorbed by the cooler building fabric. Night cooling can be selected and is controlled based on the strategy developed within BSRIA Technical Appraisal 14/96.

Solar Gains

The method outlined in CIBSE TM37 has been used to classify the solar gains to the test room in terms of solar gain per unit floor area (m^2) over the period 0630 to 1630 Solar Time (GMT). By exploring different glazing areas and shading coefficients, three levels of solar gains have been determined: Low 10 $W \cdot m^{-2}$, Medium 20 $W \cdot m^{-2}$ and High 30 $W \cdot m^{-2}$. A glazing area of 40% has been used for all of the solar gains, except when the facade faces north where a glazing area of 60% was required to achieve medium solar gains and 90% to achieve high solar gains. The shading coefficients of the glazing have been adjusted to achieve a low, medium and high configuration for north, east, south and west orientations.

Building Thermal Weight

The thermal mass is characterised by the room admittance per m^2 floor area and categorised the different levels as: Very Light 6 to $8W \cdot m^{-2} \cdot K^{-1}$, Light 8 to 10 $W \cdot m^{-2} \cdot K^{-1}$, Heavy 14 to 18 $W \cdot m^{-2} \cdot K^{-1}$ and Very Heavy 18 to 24 $W \cdot m^{-2} \cdot K^{-1}$.

To give a fair representation of this spectrum four typical groups of construction have been created allowing the user to select the level of thermal mass (see table 4.12).

Table 4.12: Typical groups of construction

Element	Very Light	Light	Heavy	Very Heavy
		$W \cdot m^{-2} \cdot K^{-1}$		
External Wall	0.85	2.73	5.53	5.53
Internal Wall	0.75	2.65	4.13	4.13
Floor	2.57	2.57	2.72	6.26
Ceiling	2.86	2.86	6.09	6.13
Admittance per m^2 floor area	6.39	8.78	14.39	17.96

Orientation

Although the selected solar gains controls the amount of solar heat gain to the space, the orientation still effects the time of day that the gains are experienced by the room. Orientations of North, East, South or West can be compared.

Additional Options

Additional to the main user selected parameters described above, the user can also select options that will affect the amount of energy consumed by the fan and the amount of energy consumed for heating and cooling.

The system pressure and the fan efficiency alter the energy consumption of the fan. If it is known at the early phases of design that long lengths of ductwork will be needed or energy efficient fans are to be used this will greatly effect the energy consumption. The system pressure and the fan efficiency can therefore be selected by the user.

The boiler efficiency and chiller coefficient of performance together with the distribution losses directly effect the energy consumption and can also be selected by the user.

Another key option the user can select is the amount of heat recovery for both heating and cooling.

Figure 4.4 shows a screen shot of the parameter selection page.

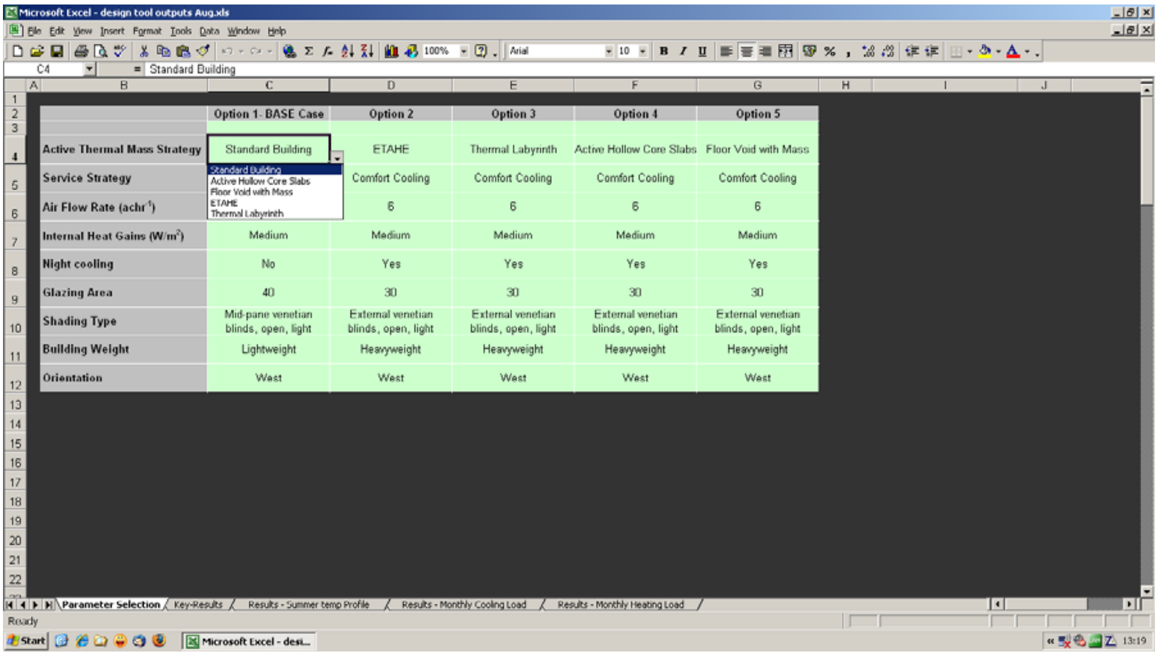

Figure 4.4 Opening tab of the concept design tool TMAir where the input parameter selection can be made.

Description of output results

The output results are presented on two different levels; summary results and detailed results.

Summary Results

The summary results are a single page printout intended to give a quick snapshot of the performance of the different options. The results are presented in a graphical format of the actual values and in a tabular format that express the results as a percentage of the base option allowing quick comparison between the different options.

Heating Energy Demand

The energy (normalised per m^2 floor area) required to maintain the test room air temperature above the heating setpoint (21^{o}C) during the occupied hours for a full year.

Cooling Energy Demand

The energy (normalised per m^2 floor area) required to maintain the test room air temperature below the cooling set point (24^{o}C) during the occupied hours for a full year. Only applies if comfort cooling is selected.

Overheating Hours

The number of hours the dry resultant temperature in the test room exceeds 24, 25, 26, 27 and 28^{o}C.

Fan Energy Demand

The energy required to run the fan to supply the air to the test room. This allows the benefits of adding night cooling to be compared against the additional energy required by the fan.

An example of the screen shot of the summary results page is shown in Figure 4.5.

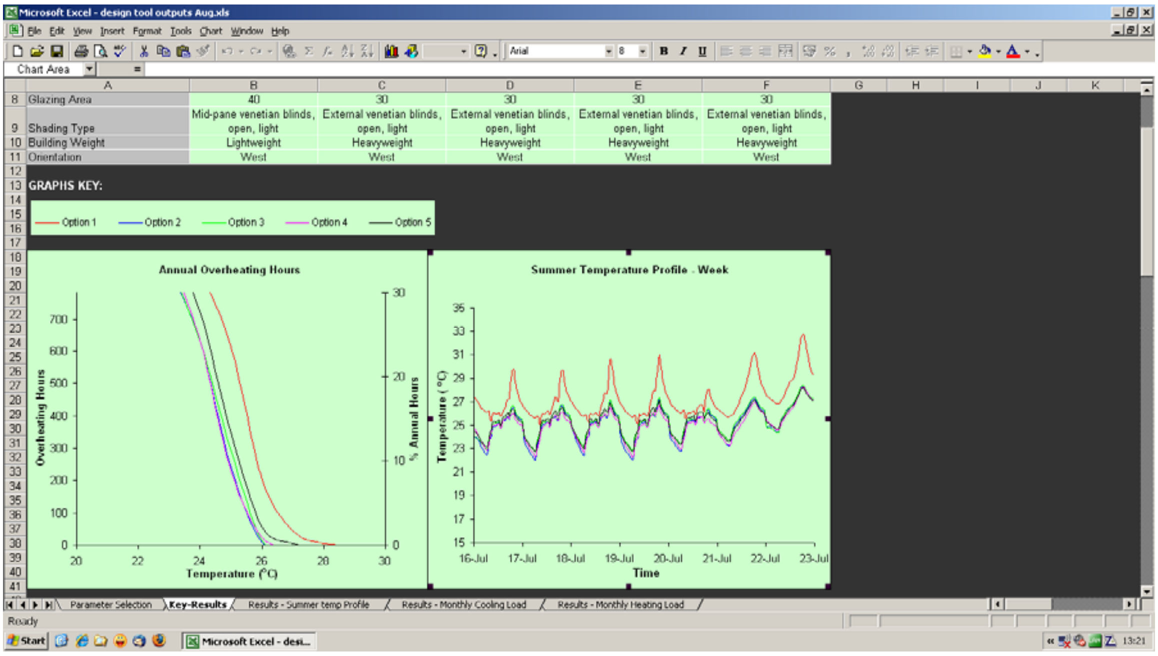

Figure 4.5: Key-results tab of the concept design tool TMAir where the annual overheating hours and the summer air temperature profile for a week are shown for the five selected options.

4.2 Detailed Results

To allow the user to look at the results in more detail there is a separate page for heating energy, cooling energy and overheating hours that break the results down into monthly energy consumption and looks at the energy and room temperatures during a peak week and a peak day. The results are again presented in a graphical format for the actual results and in a tabular format that express the results as a percentage of the base option.

Screen shots with detailed results are shown in Figures 4.6-4.8

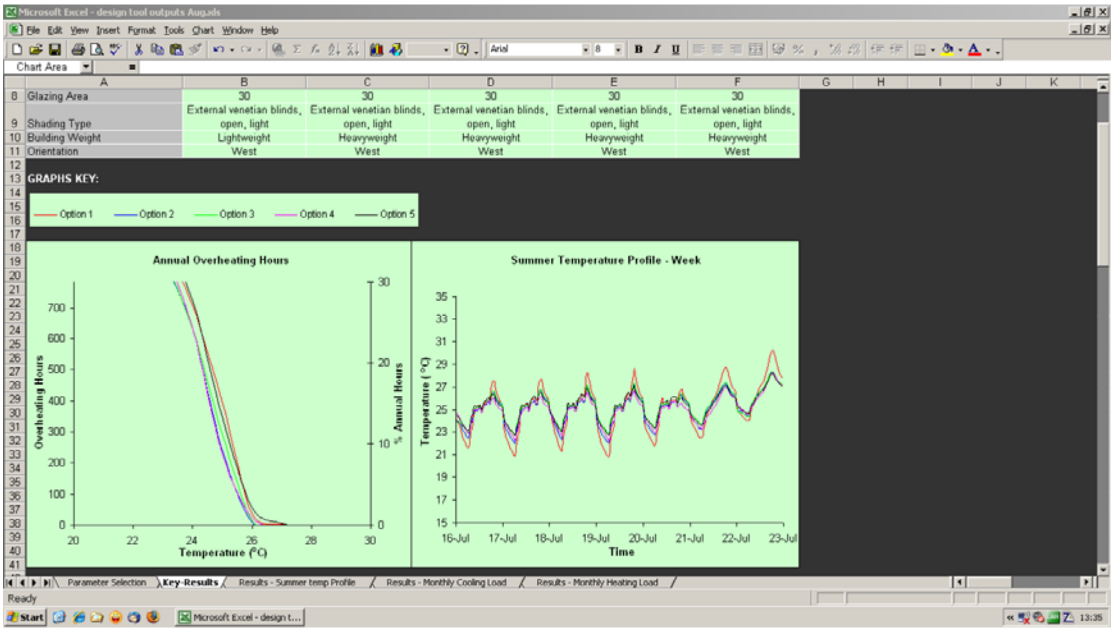

Figure 4.6 Key-results tab of the concept design tool TMAir where the annual overheating hours and the summer air temperature profile for a week are shown for the five selected options. The base-case building has input parameters exactly the same as the active thermal mass buildings.

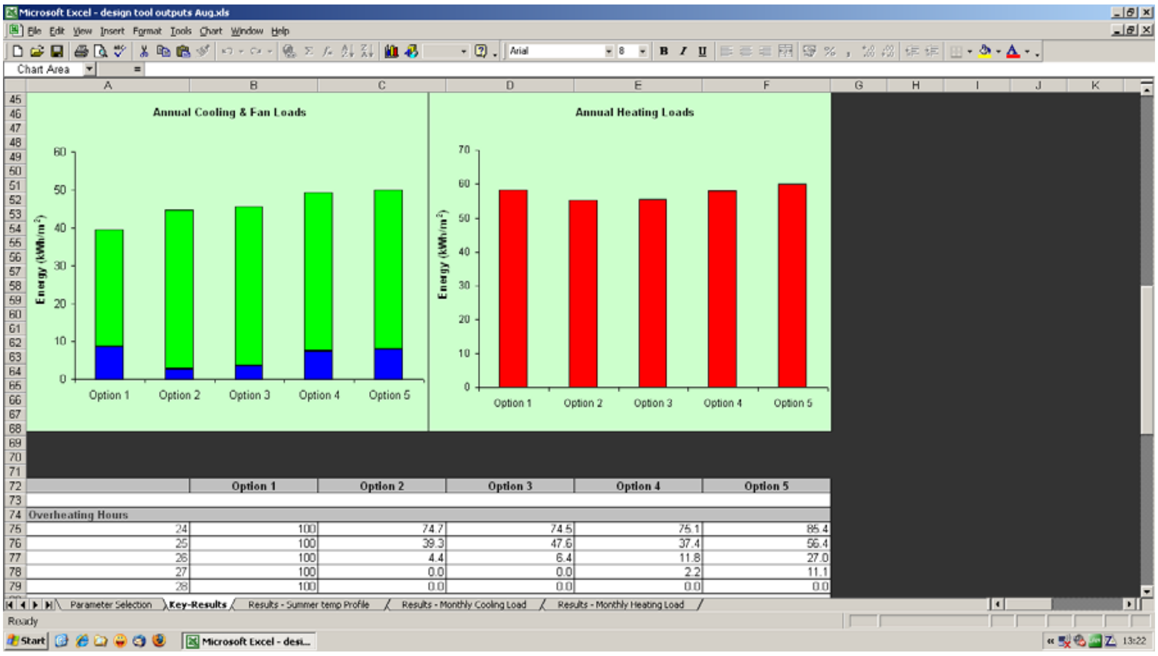

Figure 4.7 Key-results tab of the concept design tool TMAir where the energy consumption for cooling and heating are shown for the five selected options.

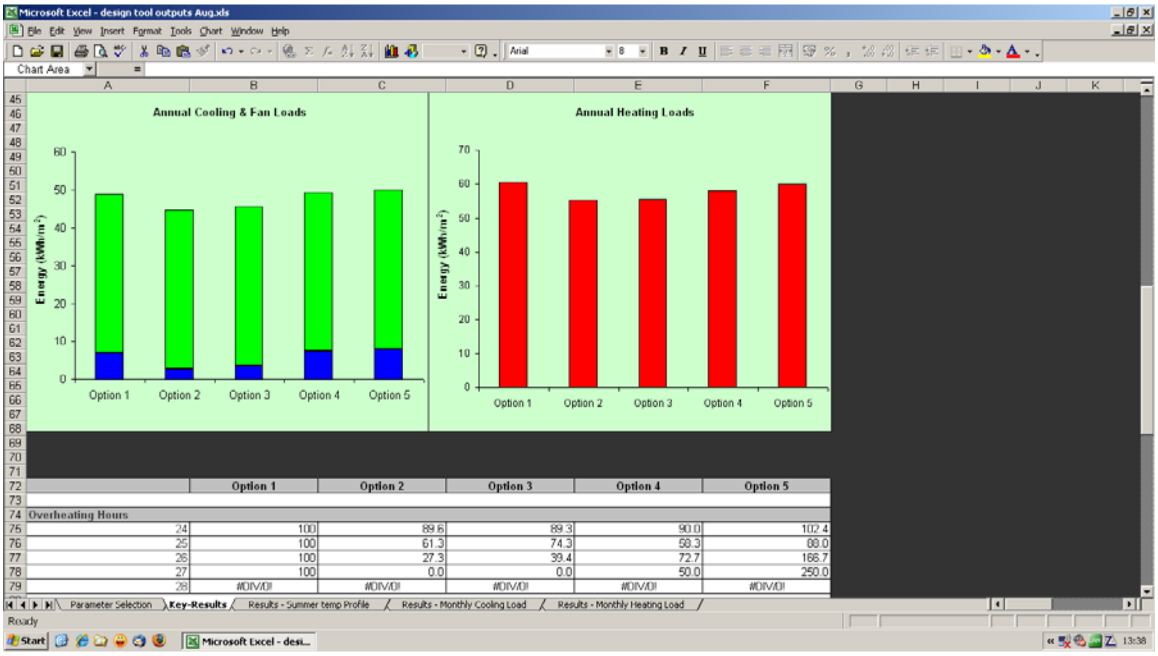

Figure 4.8 Key-results tab of the concept design tool TMAir where the energy consumption for cooling and heating are shown for the five selected options. The base-case building has input parameters exactly the same as the active thermal mass buildings.

References

1. Warwick D, Cripps A and Kolokotroni M (2008), *Integrating active thermal mass strategies with HVAC systems in office buildings:*

development of a concept design tool, AIVC conference 14-16 October, Kyoto, Japan Vol 2, pp 111-116
2. Warwick DJ, Cripps AJ and Kolokotroni M (to appear 2009), *Integrating active thermal mass strategies with HVAC systems: dynamic thermal modelling*, International Journal of Ventilation.

4.3 Methods and Tools Applicable in Phase 4

The principal areas for building energy and environmental modelling are:

- Thermal analysis – building
- Thermal analysis – system design
- Airflow

For each area a large number of computer models have been developed with varying degrees of sophistication, ranging from simple correlations derived from field measurements to dynamic numerical simulations based upon a fundamental understanding of the physical processes involved, notably heat transfer and fluid flow.

Design phase 5 as defined by Annex 44 is concerned with the evaluation of the total performance of the building and the integral effect of the selected RBEs. Therefore, thermal and environmental analysis of the building and its systems is necessary combined with the detailed consideration of the selected RBEs.

Whole Building performance evaluation tools

These models calculate the effect of climate, construction features of the building (ie built form; materials of construction; fenestration; orientation; etc) and internal heat gains on the internal environment or, alternatively, if the internal conditions are defined, the heating or cooling loads. Models may be identified as follows:

(a) Elemental

These models predict the performance of elements of the building envelope based upon either steady state or time varying heat flux. Although usually one-dimensional, some models will deal with three-dimensional heat flux such as that that occurs at the junction of building elements. If moisture transfer is included then surface and interstitial condensation can be predicted.

(b) Steady-state heat loss

These relatively simple models ignore the transient effect of solar and other gains gains and diurnal changes in outside temperature and predict building heat loss, based upon U-value, in order to assist with sizing heating plant.

(c) Quasi-dynamic analysis

These models enable the thermal inertia of the building fabric as well as its thermal conductivity to be taken into account. However, they do so by making approximations to the time varying components of the forcing functions of heat transfer, such a solar gain. These methods have their origin in methods that were originally developed for manual calculations, such as the ‘admittance procedure’, used by UK CIBSE.

(d) Dynamic analysis

This method can be used without any restrictive assumptions concerning the forcing functions of heat transfer. There are two principal approaches – (i) using response factors and (ii) finite difference techniques. Chapter 2 of Clarke (2001) contains a discussion of the relative merits of each approach.

Typical simulation tools for whole building performance evaluation

A comprehensive list of simulation tools for whole building performance evaluation can be found in the Building Energy Software Tools Directory under the 'whole-building analysis' and then 'energy simulation' and 'load calculation' where their capabilities are briefly described and links to developers are included. (http://www.eere.energy.gov/buildings/tools_directory);

A comparison of the most commonly used simulation software can be found in (Crawley et al, 2008) where the relative accuracy of prediction is discussed.

Consideration of RBEs

These whole building simulation tools would be used at the Phase 5 design of the building to optimise energy and environmental performance. Consideration of RBEs would be in the form of integration of these elements in the design in cases that such components can be simulated or the RBEs contribution can be examined through the use of available simplified tools. For example, activated thermal mass strategies can be considered for offices in the UK following the parametric analysis results described in the concept design tool in section 4.2.3. Information about the effect of RBE's considered in Annex 44 are included in Part 2 of this Guide where the state-of-are including available methods for their evaluation are discussed.

At this phase 4, iterative procedure as depicted in Figure 4.3 of section 2.3 might need to be applied if the selected RBEs prove inefficient to provide the environmental performance criteria set in Phase 3. If the indications are the environmental performance criteria are met then the final Phase 6 would begin to define and size building systems and components.

Building systems evaluation tools and tools for detailed design of RBE

In order to convert heating and cooling loads into energy consumption it is necessary to model the relevant systems and their controls. As with building thermal analysis, models may be identified by their complexity:

(a) Preconfigured system

Essentially a 'black box' approach, these are models of specific systems in which performance of a system over a range of operating variables is represented by specific mathematical relationship derived by curve-fitting to actual performance data or manufacturers' test information.

(b) Quasi-dynamic

In this approach individual components and control systems are represented by idealised equations describing their behaviour. This approach enables a closer representation of, for instance, plant modulation and parasitic energy losses.

(c) Dynamic component

This approach is similar to (b) but the dynamics of components and control systems are modelled in detail, including aspects such as the thermal inertia of heating or cooling coils.

Most whole building performance evaluation software will include system and component design facilitation so that the same software could be used in Phases 5 and 6.

Detailed design of RBE components

The detail component design and sizing of selected RBEs is also carried out at this phase. As mentioned before available software would have some facility to model such components although the detail of modelling will depend on available methods for their consideration. In some cases, methods have been developed within Annex 44, for example in the case of DSF and thermal mass activation; this is described in Part 2 of this Guide.

References

Clarke, J A (2001). Energy Simulation in Building Design. (2nd Edition). Butterworth Heinemann, 2001

Crawley D.B.,_Hand J.W., Kummert M. and Griffith B.T. (2008). Contrasting the capabilities of building energy performance simulation programs, Building and Environment 43 (2008) 661–673

4.4 Building Performance Prediction Accuracy

In the design of responsive building concepts it is crucial to be able to predict the building performance with a satisfactory accuracy, especially, when selection between alternative design solutions is needed or if the aim is to perform an optimization of the building performance. When expressed in suitable indicators as primary energy use, environmental load and/or the indoor environmental quality, the building performance simulation provide the decision maker with a quantitative measure of the extent to which the design solution satisfies the design requirements and objectives.

It is essential that the simulation result reflects the characteristics of the building and its technical systems and is able to simulate the building performance with a satisfactory accuracy - that the results are reliable and comparable. Traditionally, building performance simulation is based on a deterministic approach as described in sections 4.2 and 4.3, which implies that the spread of input parameters is zero. However, to be able to compare different design alternatives against each other it is necessary also to estimate how reliable a design is, i.e. to quantify the uncertainty that is affiliated to the simulated result of each design alternative. This can contribute to more rational design decisions. At the same time it may lead to a more robust design due to the fact that the influence of variation in important design parameters has been considered.

The different sources for uncertainties can be divided into four different categories:

- Uncertainties in the psychical model of the building and its technical systems.
    - Algorithms used in the software are simplifications/models of the physical system
    - Models for different parts of the system have typically not the same level of detail
- Uncertainties in the software and the numerical solution of equations.
    - Programming errors will always exist in detailed software tools.
    - Numerical solution of the governing equations is an approximation of the real solution.
- Uncertainties introduced by the operator of the software
    - The real system is very complex, which requires that approximations and simplifications are made. Different operators make different decisions on this
    - Operators make mistakes when running the software
- Uncertainties in selection of scenarios and parameter estimation
    - Different scenarios can be selected for simulation, as it is very difficult to predict future use of a building
    - Modeling requires a huge number of different input parameters which are not well defined
    - Lack of information may lead to the use of “educated guesses”.
    - Imprecision in the construction process and natural variability in properties of building components and materials will also occur.

The first two categories of uncertainties are dealt with and minimized in the development and validation of the simulation models and software tools, while the two last are dominating in the application phase. The following focuses on the application phase and especially on the uncertainties introduced in the selection of modeling scenarios and estimation of input parameters.

4.4.1 Description of a proposed method

An *Uncertainty Analysis* determines the total uncertainty in model predictions due to imprecisely known input variables, while a *Sensitivity Analysis* determines the contribution of the individual input variable to the total uncertainty in model predictions. The sequence of the two analysis methods is quite arbitrary as it is an iterative process, especially for large models, as it is the case for simulation of the performance of integrated building concepts.

First of all it must be decided if the uncertainty in model predictions is considerable. This is most often based on subjective judgment in the first case. Next step is a screening analysis (based on a simplified sensitivity analysis) that limits the number of investigated parameters to a manageable amount and, finally, an uncertainty analysis determines if the uncertainty is considerable. If so, a sensitivity analysis is performed to identify the most important parameters. Then these are defined more precisely and an uncertainty analysis evaluate, if the uncertainty has decreased to an acceptable level. If not, the iterative process is repeated until an acceptable level is found and/or the actual level of uncertainty is known. Usually, after the initial screening analysis it is only necessary to run the process one or two times to reach acceptable results.

Sensitivity analysis

A sensitivity analysis determines the contribution of the individual design variable to the total performance of the design solution. It can be used to ascertain which subset of design variables accounts for the most of the building performance variance (and in what percentage). Those design variables with a small percentage can be given any value within their range of variability and will result in simplification of the design task. Sensitivity analysis can be grouped into three classes: screening methods, local sensitivity methods and global sensitivity methods.

Screening methods are used for complex situations which are computational expensive to evaluate and/or have a large number of design parameters as in sustainable building design. It is an economical method that can identify and rank qualitatively the design parameters that control most of the output variability, i.e. energy performance. The methods are so-called OAT-methods (One-parameter-At-a-Time) in which the impact of changing the values of each design parameter is evaluated in turn (partial analysis). A performance estimation using “standard values” is used as control. For each design parameter, usually two extreme values are selected on both sides of the standard value. The differences between the result obtained by using the standard value and using the extreme values are compared to evaluate which design parameters the building energy performance is significantly sensitive to.

Local sensitivity methods are also often based on an OAT approach, where evaluation of output variability is based on the variation of one design parameter, while all other design parameters are held constant. This method is useful for comparison of the relative importance of various design parameters. The input-output relationship is assumed to be linear and the correlation between design parameters is not taken into account.

Global sensitivity methods are approaches where output variability due to one design parameter is evaluated by varying all other design parameters as well, and where the effect of range and shape of their probability density function is incorporated. An array of randomly selected design parameter values and calculated output values provides a means for determining the design parameter sensitivity. The influence of other design parameters is relevant to consider in sensitivity analysis since the overall building performance is of importance. Distribution effects are meaningful because design parameter sensitivity depends not only on the range and distribution of an individual design parameter, but also on other parameters to which the performance is sensitive. Design parameter sensitivity is often dependent on the interactions and influences of all design parameters.

The basic six steps in a sensitivity analysis include:

1. Identification of questions to be answered by the analysis, define output variable(s), define an appropriate model and its design parameters.
2. Determine design parameters to be included in an initial screening analysis. Perform the screening analysis and select the most important design parameters for further analysis
3. Assign probability density functions to each selected design parameter
4. Generate an input vector/matrix (maybe considering correlation) through the use of an appropriate random sampling method
5. Calculate an output distribution based on the generated input matrix
6. Assess the influence and relative importance of each design parameter on the output variable(s)

A number of different mathematical methods for sensitivity analysis can be found in the literature. Based on the available information the Morris method, (Morris, 1991), is evaluated as the most interesting for sensitivity analysis in sustainable building design as:

- The method is able to handle a large number of parameters
- It is economical – the number of simulations are few compared to the number of parameters
- It is not dependent on assumptions regarding linearity and/or correlations between parameter and model output
- Parameters are varied globally within the limits
- Results are easily interpreted and visualised graphically.
- Indicates if parameter variation is non-linear or mutually correlated.

Sensitivity analyses can in principle be used for all kinds of projects, however, the more spread found in the various design parameters and the higher the sensitivity to those parameters, the more benefit will be gained from the analyses. The sensitivity analyses will typically be performed by consulting engineers preferably at a reasonably early phase of the building design process, where it is still possible to influence the important parameters. The sensitivity analysis makes it possible to identify the most important design parameters for building performance and to focus the building design and optimization on these fewer parameters. The main barrier for application of sensitivity analysis in building performance assessment is the increase in calculation time and complexity. Even if the Morris method is relatively effective about 500 calculations of output variables are needed for an investigation of 50 variable design parameters.

1. Identification of problem and selection of calculation method

The first step in a sensitivity analysis is to identify the question(s) to be answered by the analysis, i.e. define the output variable. Often the analyses will focus on the building energy performance (e.g. kWh/(m^2 year)) and/or the indoor environmental quality (e.g. average/cumulated predicted percentage of Dissatisfied (PPD) or the number of hours during a year a certain predefined indoor temperature is exceeded, etc.). The building costs may be linked to the sensitivity analyses and form an integrated part of the entire decision process. An appropriate simulation model including its design variables is selected. Based on the output of the simulation model it should be possible to answer the identified question with the necessary accuracy. The required level of modelling detail will depend on the design phase, where the sensitivity analysis is applied, as well as on the available knowledge of design parameters. In the very early conceptual or preliminary design phases relatively simple calculation methods should be used as the design solutions are not well defined and the knowledge of design parameters limited, while at later design phases more detailed models should be used.

2. Screening of design parameters

The second step is by a screening method to determine which design parameters should be included in the sensitivity analysis. This is done by a one parameter at a time (OAT) method in which the effect of each design parameter on the building performance is evaluated in turn. A performance estimation using “standard values” for all design parameters is used as control. For each design parameter usually two extreme values are selected on both sides of the standard value. The differences between the results obtained by using the standard value and using the extreme values are compared to evaluate which design parameter is building energy performance significantly sensitive to. A design parameter can be considered to be sensitive, if its value can vary considerably. These design parameters are the ones selected for the initial screening. A simple method to determine the design parameter sensitivity is to calculate the output % difference for the extreme values of the design parameter. This “sensitivity index” can be calculated as:

$$SI = \frac{E_{max} - E_{min}}{E_{max}} 100 \qquad \% \quad (1)$$

Where E_{max} and E_{min} represent the maximum and minimum output values, respectively, resulting from varying the design parameter over its entire range. If the sensitivity index reaches a defined critical value the design parameter is considered to be important and it is included in the further analysis.

3. Assignment of probability density functions

The third step is to assign a probability density function to each design parameter, which is found to be important for building energy performance in the initial screening. In most cases it is possible to estimate the limits for the variation of a design parameter to estimate the most probable value of the parameter within the limits and to choose the most appropriate probability density function. For each design parameter the typical value chosen, variation limits and probability distribution may depend on architectural considerations, technical possibilities or limitations and/or economical consideration or other issues. Results of sensitivity analysis generally depend more on the selected ranges than on the assigned probability distributions. Typically three different probability density functions are used; Uniform, Lognormal and Normal distribution, see Figure 4.9.

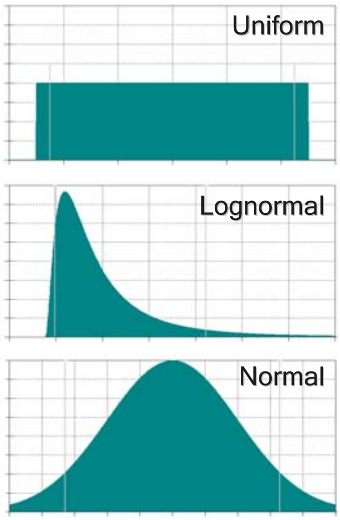

Figure 4.9. Probability density distributions usually applied in sensitivity analysis in sustainable building design.

4. Generation of design parameter input matrix

The fourth step is to generate input vectors. Various sampling procedures exist among which are: random sampling, Latin hypercube sampling and quasi-random sampling. Control of correlation between variables within a sample is extremely important and difficult, because the imposed correlations have to be consistent with the proposed variable distribution.

The factorial sampling method proposed by (Morris, 1991) is applied in this work to generate the input vectors. The method comprises a number of individually randomised one-factor-at-a-time samples of design parameters where all parameters are varied within their variable space in a way that spans the entire space to form an approximate global sensitivity analysis. Based on the probability density functions of each parameter random samples of design parameters are generated. Initially each design variable is scaled to have a region of interest equal to [0,1] according to the probability density function chosen for each variable. Each design parameter may assume a discrete number of values, called levels, *p*, with a distance of equal size, Δ.

A design parameter vector, X_i, with a number of elements equal to the number of design parameters, *k*, is assigned a random base value (on the discretized grid mentioned above). Then a path of orthogonal steps through the *k*-dimensional parameter space is "followed". The order of the steps is randomized by selecting a new randomized value for one randomized parameter at a time, while keeping all other design parameters constant. After each step a new design parameter vector is defined, see figure 4.10. This is continued until all design parameters are represented by two different values creating a set of *(k+1)* independent design parameter vectors.

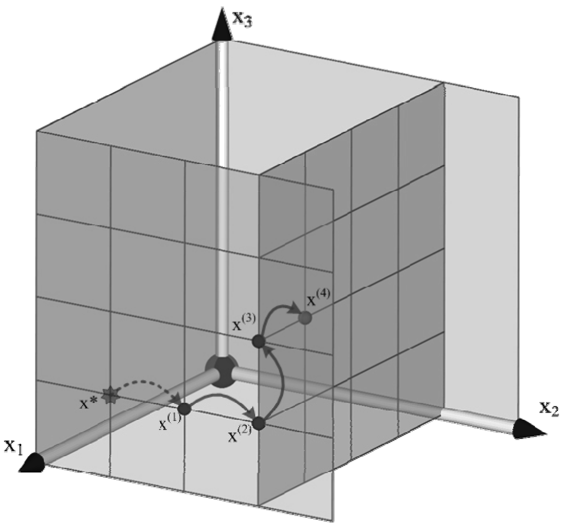

Figure 4.10. Illustration of the path of 4 orthogonal steps through a 3-dimensional parameter space to create 4 independent design parameter vector. The random base value, x*, is used as a starting point for the process.

The procedure is repeated r times creating a set of *r (k+1)* independent design parameters vectors. In order to make sure that the region of variation is reasonably covered for all design parameters a minimum value of *r* = 4 is recommended in the literature, while a value of *r* = 10 is recommended to obtain very reliable results, (JRC 2004). This means that for a case with 20 design parameters the number of design parameter vectors and corresponding simulations to calculate the output values will be in the range of 44 – 210.

5. Calculation of output variable

The fifth step is to create an output variable for each sample of design parameters represented in a design parameter vector. This is be achieved by the selected simulation model.

6. Assessment of the influence of each design parameter

The last step is the assessment of the influence of each design parameter on the expected value and the variance of the output parameter(s). A number of different techniques can be used, like rank transformation, regression analysis and scatter plots, yielding different measures of sensitivity.

The method of "Elementary Effects", (Morris, 1991), is applied in this work. The method, which can be seen as an extension of a derivative-based screening method, can be characterized as a method with global characteristics. The method has been applied in several areas of building sciences e.g. natural night ventilation, (Bressech and Janssens, 2004), and thermal building simulation, (De Wit, 1997). The main purpose of the method is to determine which design parameters may be considered to have effects which are a) negligible, b) linear and additive, or c) non-linear or involved in interactions with other factors.

The method determines the so-called elementary effect *EE* of a model $y = y(x_1,\ldots,x_k)$ with input (design) parameters x_i. The Elementary Effect for the i^{th} input parameter in a point x is:

$$EE(x_1,\ldots,x_k) = \frac{y(x_1, x_2, \ldots, x_{i-1}, x_i + \Delta, x_{i+1}, \ldots, x_k) - y(x_1, \ldots, x_k)}{\Delta} \qquad (2)$$

A number of elementary effects EE_i of each design parameter are calculated based on the generated samples of each design parameter in step four, i.e. the chosen value of *r*. The model sensitivity to each design parameter is evaluated by the mean value and the standard deviation of the elementary effects:

$$\mu = \sum_{i=1}^{r} \left| EE_i \right| / r \qquad (3)$$

$$\sigma = \sqrt{\sum_{i=1}^{r} \left| EE_i - \mu \right|^2 / r} \qquad (4)$$

where μ is the mean value of the absolute values of the elementary effects determining if the design parameter is important, and σ is the standard deviation of the elementary effects which is a measure of the sum of all interactions of x_i with other factors and of all its nonlinear effects. *r* is the number of elementary effects investigated for each parameter or the number of repetition of the procedure in step four.

The result of the sensitivity analysis is a list of important design parameters and a ranking of the design parameters by the strength of their impact on the output, μ.

Uncertainty analysis

To estimate simulation uncertainty Monte Carlo analysis are often used. By generating a series of random combinations of input parameters the simulation results can be used to determine both uncertainty in model predictions and apportioning to the input parameters their contribution of this uncertainty.

A Monte Carlo analysis involves a number of steps. The first step is based on the probability density functions of each parameter to generate random samples of input parameters. Various sampling procedures exist among which are: random sampling, Latin hypercube sampling and quasi-random sampling. Control of correlation between variables within a sample is extremely important and difficult, because the imposed correlations have to be consistent with the proposed variable distribution. A method is proposed by Iman and Conover (1982). The second step is the evaluation of the model for each sample of input parameters. The third step is the uncertainty analysis, where the expected value and the variance for the output parameter(s) are estimated. The final step is the sensitivity analysis to apportion the variation in the output to the different sources of variation in the system. A number of different techniques can be used, like rank transformation, regression analysis and scatter plots, yielding different measures of sensitivity, Saltelli et al. (2000).

Uncertainty and sensitivity analyses can in principle be used for all kinds of projects, however, the more spread found in the various input parameters and the higher the sensitivity to those parameters, the more benefit will be gained from the analyses. For instance, it will obviously be more beneficial to perform an uncertainty analysis for a naturally ventilated light building than for a traditional fully air-conditioned heavy type of building.

The UA/SA analyses will typically be performed by consulting engineers preferably at a reasonably early phase of the building process where it is still possible to influence the important parameters. It may be very useful to apply the analysis at two phases; for the initial design where the overall important parameters are determined and later on when the detailed design is worked out and, for instance, the building services are considered.

The analyses will usually focus on the building energy consumption (e.g. kWh/(m^2 year)) and the indoor environmental quality (e.g. average/cumulated PPD, number of hours exceeding a certain predefined temperature etc.). The building costs may be linked to the UA/SA analyses and form an integrated part of the entire decision process.

4.4.2 Examples of Application

Sensitivity analysis in concept design

In order to illustrate the application of the method described and its potential benefits in an integrated design process, it is demonstrated on a conceptual design proposal for a 7 storey office building.

The office building consists of a ground floor, which is larger than the six upper floors. An atrium is placed in the southern façade from ground floor to the roof, see figure 4.11. The ground floor measures 24,0 m × 32,4 m and is mainly used for an entrance hall, restaurant, office, conference room, cafe and technical appliances. Stairways, toilets and elevators are placed in the centre of the building. The upper floors, measuring 24,0 m × 24,0 m, are conceptually made in the same way although there are slight differences. The 2nd, 4th and 5th floor are designed with the same layout, see Figure 4.11. The height of each story is 3,5 m, which gives a total building height of 24,5 m. The gross floor area is A_{gross} = 4233,6 m^2. The heated floor area is A = 3910,8 m^2. The areas of the zones in the building on each floor are listed in Table 1. The ground floor includes a restaurant with a large glaced area. On the south facade of the building the atrium facade has glazing running continuously from the ground level to the 6th floor. In Table 4.13 the total window area of each floor, including the atrium, is listed as well as the orientation of the windows. The window area relative to the heated floor area is 17 %.

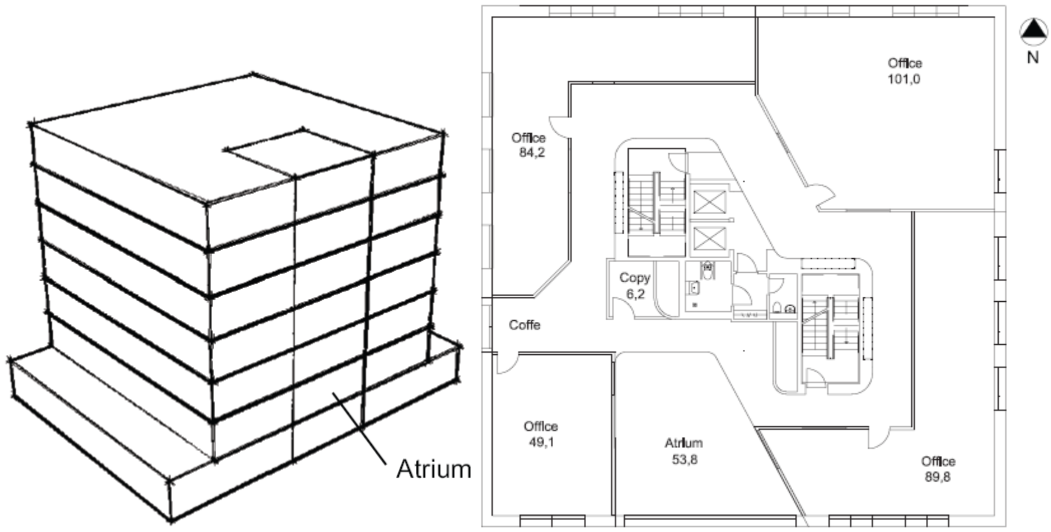

Figure 4.11. Sketch and Plan drawing of building.

Table 4.13. Floor area of building zones.

	Gr.	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}
Conference room	100,1	0	0	0	0	0	0
Offices	112,1	237,6	324,1	315,5	324,1	324,1	182,8
Copy rooms	6,5	12,8	6,2	12,8	6,2	6,2	12,8
Café	52,3	0	0	0	0	0	128,4
Restaurant	126,0	38,6	0	0	0	0	0
Kitchen	40,8	37,0	0	0	0	0	0
Technical rooms	7,0	0	0	6,2	0	0	6,2
Administration	22,1	0	0	0	0	0	0
Corridors	235,7	121,2	116,9	112,7	116,9	116,9	117,0
Toilets	7,4	7,4	7,4	7,4	7,4	7,4	7,4
Building core	67,6	67,6	67,6	67,6	67,6	67,6	67,6
$\sum$	777,6	522,2	522,2	522,2	522,2	522,2	522,2

Table 4.14. Window area and direction

Floor	North $[m^2]$	East $[m^2]$	South $[m^2]$	West $[m^2]$
Ground floor	29,7	12,8	47,3	20,8
1. floor	20,2	12,8	46,1	14,2
2. floor	19,2	12,8	46,1	12,8
3. floor	20,9	12,8	46,1	12,8
4. floor	19,2	12,8	46,1	12,8
5. floor	19,2	12,8	46,1	12,8
6. floor	20,2	12,8	46,1	12,8
$\sum$	148,6	89,6	323,9	99,0

The total energy use for heating, ventilation, cooling and lighting in the reference building is calculated by the software programme BE06 to be *E = 107.4 kWh/m² year* (heating 45,9 kWh/m² year, ventilation 33,5 kWh/m² year, cooling 0 kWh/m² year and lighting 28,0 kWh/m² year). This is above the present requirements (95 kWh/m² year) and some changes in the actual design are necessary in order to reduce the energy use to reach the future requirements.

Results of analysis

A sensitivity analysis was performed to identify the important design parameters to change in order to reduce the energy use in the reference building. In the analysis a series of parameters were changed and the effect of the changes on the demand for heating, cooling and total energy were evaluated by the software package BE06.

Table 4.15 shows the design parameters included in the analysis and for each parameter the defined range and distribution. For some design parameters the probability density function is given as a normal distribution defined by its mean value and the standard deviation. For other design parameters a uniform distribution is defined by four discrete values. For each design parameter 4 different elementary effects are used, i.e. that for each parameter 4 values of the output variable (energy use) are obtained. With 21 parameters, the minimum number of simulations using Morris' Randomized OAT Design as a Factor Screening Method for Developing Simulation Metamodels:

$N = r \times (k + 1) = 4 \times (21 + 1) = 88 \quad (5)$

where

N is the number of simulations
r is the number of elementary effects per factor
k is the number of design parameters

Instead of using the minimum number of simulations 10 paths through the design parameter space are explored to give more accurate results. With this number of elementary effects for each parameter, the number of simulations becomes 220.

For the design parameters given in the unit percent in Table 4.15 the discrete values are the percentage of the values used in the reference building. The usage factor and the installed power concern the lighting zones in the building. The numbers 1 to 4 for the lighting control system refer to *N*one control, *M*anual control, *A*utomatic control and *C*ontinuous control in BE06.

Table 4.15. Design parameters for sensitivity analysis, their range and distribution.

	Parameter	Unit	Discrete values				μ	σ
1	heat capacity	$\left[\frac{Wh}{K\,m^2}\right]$					120	10
2	U (climate shield)	[%]	100	83,3	66,7	50		
3	Line loss	[%]	100	66,7	33,3	0		
4	U (windows)	$\left[\frac{W}{m^2K}\right]$	1,5	1,3	1,1	0,9		
5	g-value	$[n.d.]$	0,7	0,6	0,5	0,4		
6	Shading	[-]	0,8	0,6	0,4	0,2		
7	Overhang	[°]	45	30	15	0		
8	q_m	$\left[\frac{l}{s\,m^2}\right]$	0	1	2	3		
9	η_{VGV}	[-]	0,7	0,75	0,8	0,85		
10	q_n	$\left[\frac{l}{s\,m^2}\right]$	0	0,15	0,3	0,45		
11	$q_{i,n}$	$\left[\frac{l}{s\,m^2}\right]$	0	0,1	0,2	0,3		
12	SFP	$\left[\frac{kJ}{m^3}\right]$	2,1	1,7	1,3	0,9		
13	$q_{m,s}$	$\left[\frac{l}{s\,m^2}\right]$	0	1	2	3		
14	$q_{n,s}$	$\left[\frac{l}{s\,m^2}\right]$	0	1	2	3		
15	$q_{m,n}$	$\left[\frac{l}{s\,m^2}\right]$	0	1	2	3		
16	$q_{n,n}$	$\left[\frac{l}{s\,m^2}\right]$	0	1	2	3		
17	Heat loads	$\left[\frac{W}{m^2}\right]$					14	2
18	Lighting power	$\left[\frac{W}{m^2}\right]$	7	8	10	11		
19	Daylight factor	[-]					2	0,5
20	Light control	[-]	1(N)	2(M)	3(A)	4(C)		
21	Usage factor	[-]	1,0	0,9	0,8	0,7		

The parameters in Table 4.15 are:

q_m is the mechanical rate during daytime in winter
η_{VGV} is the efficiency of the heat recovery
q_n is the natural ventilation rate during daytime in winter
$q_{i,n}$ is the infiltration rate during nighttime in winter
SFP is the specific fan power
$q_{m,s}$ is the mechanical rate during daytime in summer
$q_{n,s}$ is the natural ventilation rate during daytime in summer
$q_{m,n}$ is the mechanical rate during nighttime in summer
$q_{n,n}$ is the natural ventilation rate during nighttime in summer
g is the relation between the solar radiation transmitted to the room and the solar radiation reaching the window

The results of the sensitivity analysis are shown in Figure 4.12. The figure shows the mean value, μ, of the absolute values of the elementary effects determining if the design parameter is important, and the standard deviation, σ, of the elementary effects which is a measure of the sum of all interactions of x_i with other factors and of all its nonlinear effects. The dotted wedge in the figure shows the following relation between the mean value and the standard deviation:

$$\sigma = \frac{\mu\sqrt{r}}{2} \qquad (6)$$

where

σ is the mean value of the elementary effect (*kWh/m² year)*
r is the number of elementary effects per design parameter
μ is the standard deviation of the elementary effect (*kWh/m² year)*

The minimum value of *r* = 4 recommended in the literature is used in this example, (JRC, 2004) and the dotted wedge in figure 4.12 becomes σ = *μ.*

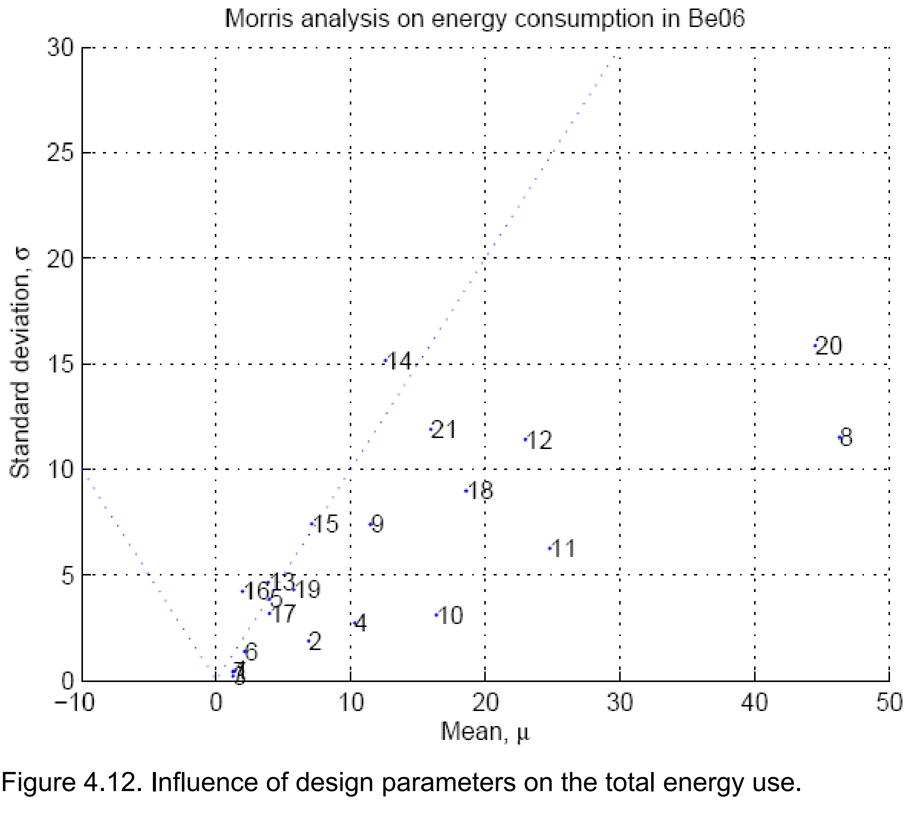

Figure 4.12. Influence of design parameters on the total energy use.

The location of a point (μ,σ) compared to the wedge given by the above equation provides information about the characteristics of that design parameter. If the point is placed inside the wedge the design parameter has mainly a correlated or/and a non-linear impact on the output (energy use). If the point for a design parameter is placed outside and far from the wedge the impact can be considered as linear and a change in the design parameter would give a proportional change of the output (energy use). If the point is located close to the lines of the wedge it is combination of the two cases.

From the results shown in Figure 4.12 it is possible to estimate the influence of each of the design parameters. It is seen that for most of the important parameters the influence on energy use is nearly linear, meaning the impact is almost the same in the whole parameter range. A ranking of the design parameters influence on the sensitivity of the energy use is listed in Table 4.16. From the ranking it can be concluded, that especially design parameters related to the artificial lighting system and the ventilation system of the building in the winter (heating) season have a significant mean value and therefore a significant influence on the energy use. Also the U-values, especially for the windows, have a notable influence.

Table 4.16. Ranking of design parameters according to their impact on primary energy use.

Rank	Parameter		μ
1	8	q_m	46,30
2	20	Lighting control	44,84
3	11	$q_{i,n}$	24,78
4	12	SFP	22,96
5	18	Lighting power	18,56
6	10	q_n	16,36
7	21	Usage factor	15,94
8	14	$q_{n,s}$	12,58
9	9	η_{VGV}	11,46
10	4	U (windows)	10,28
11	15	$q_{m,n}$	7,08
12	2	U (climate shield)	6,86
13	19	Daylight factor	5,76
14	5	g-value	3,96
14	17	Heat loads	3,96
16	13	$q_{m,s}$	3,86
17	6	Shading	2,12
18	16	$q_{n,n}$	1,96
19	1	Heat capacity	1,36
20	3	Line loss	1,24
21	7	Overhang	1,22

The sensitivity analysis was also performed with the heating demand as the output parameter. The results of this are shown in Figure 4.13.

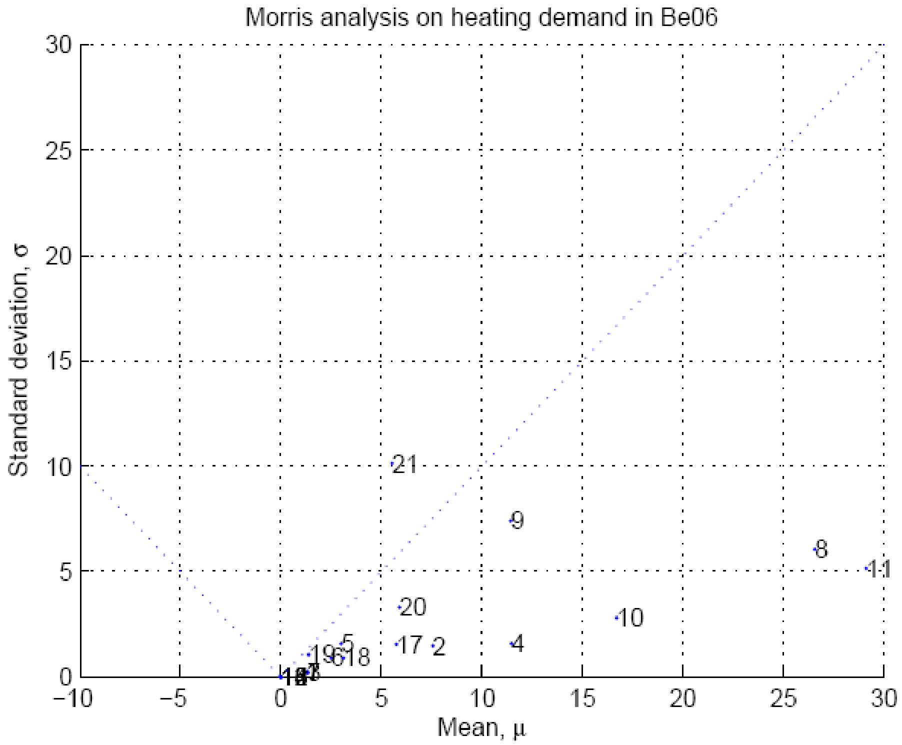

Figure 4.13. Influence of design parameters on the heating demand.

Discussion

In the calculation of the primary energy use of the reference office building it was shown that the heating demand (45,9 kWh/m^2 year) was dominating while the ventilation (33,5 kWh/m^2 year) and lighting (28,0 kWh/m^2 year) demand was slightly lower and no demand for cooling existed.

The sensitivity analysis shows which design parameters are the most important ones to change in order to reduce the energy consumption. The results show that lighting control and the amount of ventilation during winter are the two most important parameters that will have the largest effect on the energy use. This means that introduction of lighting control according to daylight levels and demand controlled ventilation in the heating season are two technologies that should be considered in the next design step.

It can also be seen that even if the heating demand is dominating the ranking of design parameters reducing the heat loss from the building are quite low. If an analysis is done for the heating demand alone instead of for the total energy use it can be seen from figure 4.13 that the ranking of parameters change a lot. Now design parameters related to ventilation in the heating season is the most important ones, while improvement of insulation levels and cold bridges still only will have a minor influence.

As the cooling demand does not exist it can also be seen that design parameters influencing the heat load of the building naturally have the lowest ranking.

It can be concluded that a sensitivity analysis in the early phases of the design process can give important information about which design parameters to focus on in the next phases of the design as well as information about the unimportant design parameters that only will have a minor impact on building performance.

The sensitivity analysis will improve the efficiency of the design process and be very useful in an optimization of building performance.

4.4.3 Benefits and barriers

The uncertainty analysis makes it possible to identify the most important parameters for building performance assessment and to focus the building design and optimization on these fewer parameters.

The results give a much better background for evaluation of the design than a single value (uncertainty quantified), which often is based on cautious selection of input parameters and therefore tends to underpredict the potential of passive technologies.

In many cases evaluation of a design solution is based on a calculation of the thermal comfort expressed by a performance indicator like PPD and/or the number of hours the temperature is higher than a certain value. Due to complexity of modelling of buildings and technical systems and the variation of boundary conditions and possible user scenarios, it is actually irresponsible to base decisions on a single calculation using a single sample of input parameters. An uncertainty analysis gives much more information about the performance and a much better background to make decisions.

The main barrier for application of uncertainty analysis in building performance assessment is the increase in calculation time and complexity. Even if the Morris method is relative effective for screening analyses about 500 calculations are needed for an investigation of 50 variable input parameters.

Monte Carlo simulation is attractive for the uncertainty analysis, as the only requirement is that it is possible to describe the probability density function of the important input parameters. The disadvantage of the method is the high number of simulations. Even if an appropriate sampling procedure is selected the number of simulations to investigate the uncertainty is 2 – 5 times the number of parameters investigated with a total number of realizations not lower than 80 - 100.

Uncertainty analysis is far from being a central issue in consultancy. Explicit appraisal of uncertainty is the exception rather than the rule and most decisions are based on single valued estimates for performance indicators. At the moment experiences from practical design cases are almost nonexistent. These are needed to demonstrate the benefits and transform the methods to practice, i.e. include uncertainty analysis in commercially available building simulation tools.

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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)

Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low-exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning
Annex 49: Low Exergy Systems for High Performance Built Environments and Communities
Annex 50: Prefabricated Systems for Low Energy / High Comfort Building Renewal
Annex 51: Energy Efficient Communities
Annex 52: Towards Net Zero Energy Solar Buildings (NZEBs)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods

Working Group - Energy Efficiency in Educational Buildings (*)

Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
(*) - Completed

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